Olympic Valley Creek/Aquifer Study Final Report

Prepared for:
Squaw Valley Public Service District

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Executive Summary

HydroMetrics WRI was retained by the Squaw Valley Public Service District to complete a Squaw Creek/Aquifer interaction study. This study enhances the District's understanding of the Valley's hydrology, and provides guidance on how to avoid negative impacts to Squaw Creek. Direct drivers of the study included:

- Satisfying California's State Water Resources Control Board Resolution 2007-0008 that, "Directs the Lahontan Water Board to continue to support the efforts of entities pumping groundwater to … conduct a study of potential interaction between groundwater pumping and flows in Squaw Creek."
- Addressing Element 2.2 of the *Olympic Valley Groundwater Management Plan,* which identifies the need for a stream/aquifer interaction study.
- Responding to demands by some members of the Squaw Valley community to gain a better understanding of the hydrologic relationship between pumping in the aquifer and flows in Squaw Creek.
- Providing the basis for a Pumping Management Plan, so the District can perform its operations with informed, best practices.
- Implementing the District's mission statement of " ... [providing] leadership in maintaining and advocating for needed, high-quality and financially sound community services for the Valley … while protecting natural resources and the environment."

The study was designed to better understand the relationship between shallow groundwater and flows in Squaw Creek. The analysis evaluated impacts of municipal well pumping on shallow groundwater adjacent to Squaw Creek, and assessed the quantity of water lost from the shallow aquifer into Squaw Creek.

The study was completed in two phases. Phase I comprised instrumentation, testing, and data collection. Phase II included analyzing data, quantifying the flows between Squaw Creek and the shallow aquifer, integrating information from multiple studies, and updating the groundwater model. The study is based on data collected through 2011, and therefore does not analyze groundwater pumping proposed in the *Village at Squaw Valley Specific Plan* (Squaw Valley Real Estate LLC, 2014). The analyses of streamflow capture was, however, applied to 2012 and 2013 Squaw Creek flow data in order to illustrate how the study's results are applicable to recent data.

The study established that water seeps both from the shallow aquifer into the trapezoidal channel, and from the trapezoidal channel into the aquifer. The direction and amount of seepage depend on both the time of year and location in the trapezoidal channel. The middle of the trapezoidal channel, near the Village East Bridge, gains water from the aquifer during spring and early summer, and then starts to lose water to the aquifer in middle summer. During late summer and early fall, the creek is dry and neither gains nor loses water to the aquifer. In autumn, the creek fills quickly, and begins to gain water from the aquifer again. The eastern edge of the trapezoidal channel, near Papoose Bridge, appears to always lose water to the aquifer. The maximum estimated creek inflow rate (creek gain) is 0.18 cubic feet per second (cfs) for each 1,000 feet of trapezoidal channel. The maximum estimated creek outflow rate (creek loss) is 0.27 cfs for each 1,000 feet of trapezoidal channel.

The two aquifer tests performed on well SVPSD#2 allowed us to estimate the amount of depletion in Squaw Creek's flow due to pumping. Streamflow depletion due to pumping changes over time. When a well is first turned on it pumps water out of the aquifer immediately adjacent to the well. As pumping continues, the well draws water from areas closer to the creek. Therefore, creek depletion from pumping is small initially, and grows over time. During an eight hour pumping cycle, well SVPSD#2 captures an average of 1.12% of its total discharge from Squaw Creek. Assuming an average pumping rate of 300 gpm, well SVPSD#2 captures an average of 3.4 gpm, or less than 0.008 cfs during a customary 8-hour pumping cycle.

The results from the well SVPSD#2 aquifer tests were applied to all active SVPSD pumping wells to obtain similar well depletion estimates. The total streamflow depletion from pumping the four SVPSD wells ranged between 0.005 cfs and 0.017cfs during water years 2012 and 2013. These relatively small stream depletion rates mean that wells only capture a significant portion of streamflow during extremely low creek flow periods. During most times, wells capture one percent or less of streamflow. In water year 2012, wells captured one percent or less of measured streamflow in 337 of the 365 days. In water year 2013, wells captured one percent or less of measured streamflow in 348 of 365 days.

In mid-summer, there are only three to seven days when pumping captures more than one percent of streamflow. Therefore, District pumping may cause the trapezoidal channel to dry out between three and seven days earlier than it would with no pumping. Lack of streamflow in western Olympic Valley is therefore not primarily caused by municipal pumping, although its onset may be hastened by approximately one week by pumping. This is supported by historical photographs that show how western Squaw Creek dried out prior any significant development.

The same pumping and streamflow capture calculations show that approximately 2% of SVPSD's total pumping is derived from reduced streamflow. This number does not account for groundwater that may be flowing towards the trapezoidal channel, but is intercepted by wells before it gets there.

The interaction between Squaw Creek and the shallow aquifer was further informed by studies conducted by Lawrence Livermore National Laboratory (LLNL) and California State University East Bay (CSUEB). The LLNL studies focused on groundwater/creek interactions in the meadow section of the Valley. Results of these studies suggested the following:

- Groundwater discharge in the meadow constitutes between 5% of total stream discharge near the peak of spring snowmelt, to nearly all of the observed flow during late summer in the meadow portion of Squaw Creek.
- Groundwater inflow into Squaw Creek is not localized in discreet areas in the meadow, but is distributed evenly throughout the meadow. Groundwater flow along geologic structures such as faults is not a significant component of the groundwater inflow to Squaw Creek.

The LLNL studies furthermore concluded that groundwater moves through the meadow much more slowly than it moves through the western portion of the basin. This has two important implications.

1. There is limited time to respond to groundwater quality threats in the western portion of the basin because groundwater moves quickly towards municipal wells. Therefore, recharge areas in the western basin should be protected from potential groundwater quality impacts. Additionally, because of the high susceptibility of municipal wells to any groundwater contamination, a secondary source of supply should be investigated to provide reliability and redundancy.
2. Groundwater pumping in the meadow has a slower, but more prolonged impact on creek flows than pumping in the western basin. Groundwater pumping in the meadow may, therefore, have a more significant impact on baseflow than pumping in the western basin.

Isotope data collected by LLNL demonstrate that most water pumped by SVPSD's municipal wells is recharged along the edges of the Valley floor, rather than through the creek bed. The average elevation of the recharge zone is approximately 6,300 feet msl. This elevation is generally found just above the Valley floor. This furthermore suggests that limited groundwater is derived from deep fracture flow entering the Valley.

Based on the results of the Creek/Aquifer interaction study and the LLNL studies, we suggest that the District prepare a pumping management plan that incorporates the data and results from the Creek/Aquifer study. This plan will allow the District to provide municipal water supplies while minimizing environmental impacts. This plan should identify pumping strategies that can be implemented with the anticipated wellfield that may result from new development in the Valley, and should guide new well placement. This plan will set guidelines for how pumping could be moved around the Valley throughout the year to minimize environmental impacts.

The District should furthermore map and protect the primary groundwater recharge zones. This mapping is a recent requirement of Groundwater Management Plans. The LLNL studies suggested that most recharge occurs at an average elevation of 6350 feet. Mapping recharge zones is an inexact exercise, but additional mapping efforts may help locate important recharge areas. The mapped recharge zones should be maintained as protected, and potentially enhanced, recharge areas.

SECTION 1
BACKGROUND

HydroMetrics WRI was retained by the Squaw Valley Public Service District to complete a Squaw Creek/Aquifer interaction study. The study enhances the District's understanding of the Valley's hydrology, and provides guidance on how to avoid negative impacts to Squaw Creek. Direct drivers of the study included

- Satisfying California's State Water Resources Control Board Resolution 2007-0008 that, "Directs the Lahontan Water Board to continue to support the efforts of entities pumping groundwater as well as other stakeholders in Squaw Valley to: . . . conduct a study of potential interaction between groundwater pumping and flows in Squaw Creek.
- Addressing Element 2.2 of the *Olympic Valley Groundwater Management Plan,* which identifies the need for a stream/aquifer interaction study.
- Responding to demands by some members of the Squaw Valley community to gain a better understanding of the hydrologic relationship between pumping in the aquifer and flows in Squaw Creek.
- Informing and providing the basis for a pumping management plan so the District can perform its operations with informed, best practices.
- Implementing, the District's mission statement of " ... [providing] leadership in maintaining and advocating for needed, high-quality and financially sound community services for the Valley … while protecting natural resources and the environment."

The study was designed to better understand the relationship between shallow groundwater and flows in Squaw Creek. The analysis evaluated impacts of municipal well pumping on shallow groundwater adjacent to Squaw Creek, and assessed the quantity of water lost from the shallow aquifer into Squaw Creek. The project's specific goals were to:

- Improve and quantify our understanding of interactions between Squaw Creek and the valley's aquifer;
- Diminish groundwater pumping impacts on Squaw Creek and the Truckee River; and to
- Increase groundwater storage in Olympic Valley.

The study focused on the Western half of Olympic Valley because that is where the vast majority of municipal pumping occurs. The study was completed in two phases. Phase

I comprised instrumentation, testing, and data collection. Phase II included analyzing data, quantifying the flows between Squaw Creek and the shallow aquifer, integrating information from multiple studies, and updating the groundwater model. The results from Phase I and Phase II provide guidance on how municipal pumping should be managed to minimize impacts on Squaw Creek. A formal wellfield optimization is yet to be completed. This optimization will result in formal recommendations on wellfield operations. This optimization will be completed after impending modifications to the wellfield layout are agreed upon.

SECTION 2
PHASE I RESULTS

Activities undertaken as part of the Phase I study included:

- Installing monitoring wells adjacent to Squaw Creek
- Instrumenting new and existing monitoring wells with data loggers
- Installing temperature probes and temporary piezometers in the trapezoidal channel
- Collecting water temperature and water level data from the trapezoidal channel over a number of months
- Conducting two aquifer tests

Full results from the Phase I studies are documented in the *Squaw Valley Creek/Aquifer Interaction Study Final Report (Phase I)* (HydroMetrics WRI 2010). The final Phase I report is included as an appendix to this report. The following sections highlight the significant activities and results from the Phase I study.

2.1 MONITORING WELL INSTALLATION

Four monitoring wells were installed adjacent to Squaw Creek. The four wells are installed at two locations, with each location comprising a shallow and a deep monitoring well. The monitoring well locations are shown in Figure 1.

The wells are placed to allow comparison of shallow groundwater elevation and creek flows. The shallow well at each location is designed to screen the shallow aquifer at the same elevation as the nearby Squaw Creek. The deep well at each location is designed to screen the deepest part of the aquifer.

Groundwater elevation data collected from the monitoring wells often show groundwater elevations in the deep wells are higher than groundwater elevations in the shallow wells. This results in a significant vertical upward gradient in the spring and summer (Figure 2). These upward gradients suggest two things. First, some groundwater enters the basin at depth. Second, the groundwater entering the basin at depth does not readily flow upward into the shallow aquifer; there is some level of confinement in the deeper aquifer.

Figure 1: New Monitoring Well Locations

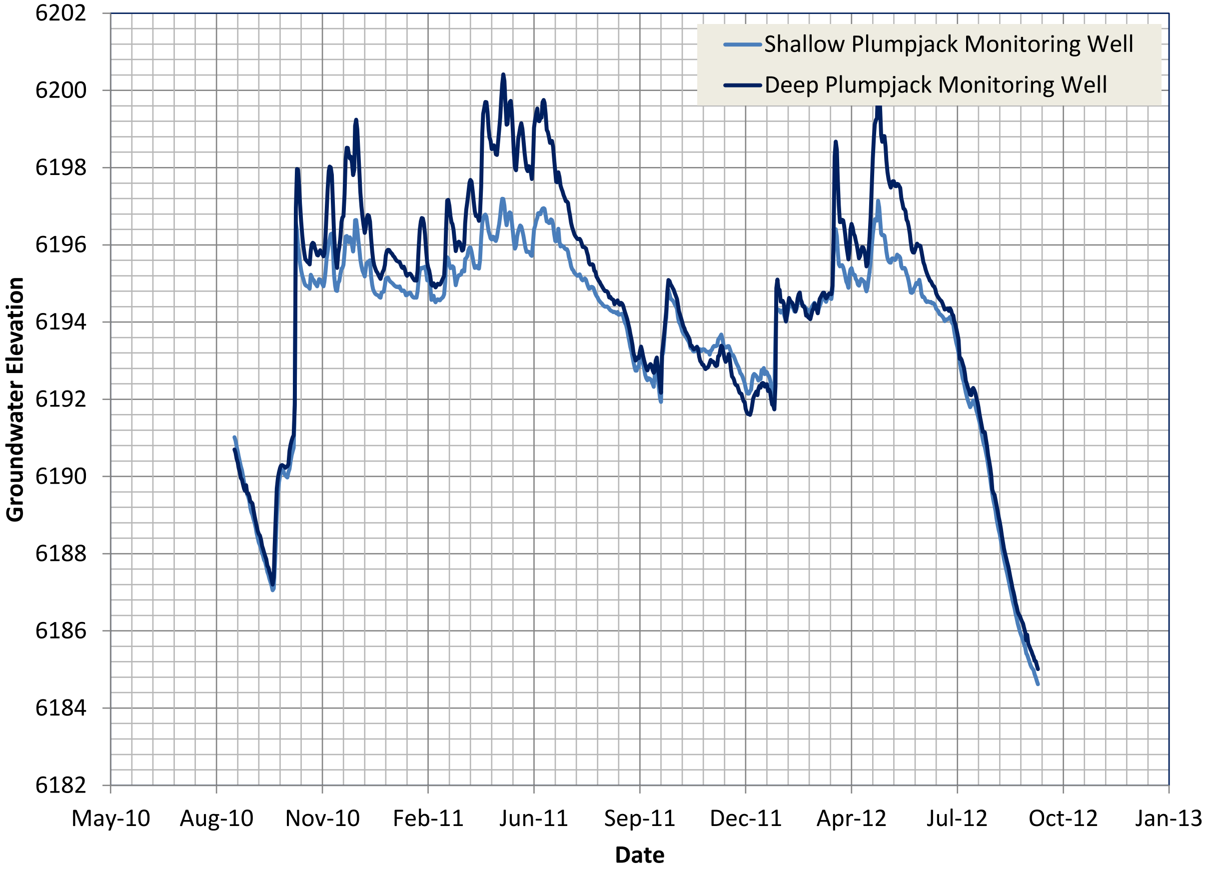

Figure 2: Plumpjack Monitoring Well Groundwater Elevation Data

2.2 TEMPERATURE PROBE AND TEMPORARY PIEZOMETER INSTALLATION

Six temporary temperature probes, four temporary piezometers, and two stilling wells were installed in Squaw Creek to measure the water flow between Squaw Creek and the adjacent shallow aquifer. These probes were installed in two sets in the trapezoidal channel: one set of probes located near Village East Bridge, and one set of probes located near the Papoose Bridge at the eastern end of the trapezoidal channel. The locations of the two sets of probes are shown on Figure 3. Cross-sections of each group of instruments are drawn in Figure 4 and Figure 5. These figures are drawn to scale in the vertical direction but not in the horizontal direction. The horizontal blue line on these figures represents a hypothetical water level in the creek. The relative horizontal position of each instrument is approximate.

Temperature probes were based on a design provided by Dr. Andrew Fisher from the University of California, Santa Cruz (personal communication). The probes were designed to measure ambient groundwater temperature at three different depths below the streambed. This design has been developed to collect data that can be analyzed using the techniques outlined in Hatch et al. (2006).

2.3 PERMANENT AND TEMPORARY DATA LOGGER INSTALLATION

Permanent data loggers were installed in 12 monitoring wells that are adjacent to Squaw Creek. The purpose of these data loggers is to continuously record shallow and deep groundwater elevations that can be compared to nearby and creek levels. These data will help evaluate the interaction between shallow groundwater and Squaw Creek. The permanent data loggers are currently programmed to record water elevations every 15 minutes.

Temporary data loggers were installed in the temporary piezometers and stilling wells installed in the trapezoidal channel. One data logger was installed in each of the four piezometers, and each of the two stilling wells. The temporary data loggers began recording data on May 23, 2009, and were removed at the conclusion of the Phase I study on November 4, 2009. The locations of monitoring wells and piezometers outfitted with of the permanent and temporary data loggers are shown in Figure 6.

Figure 3: Temperature Probe and Stream Piezometer Locations

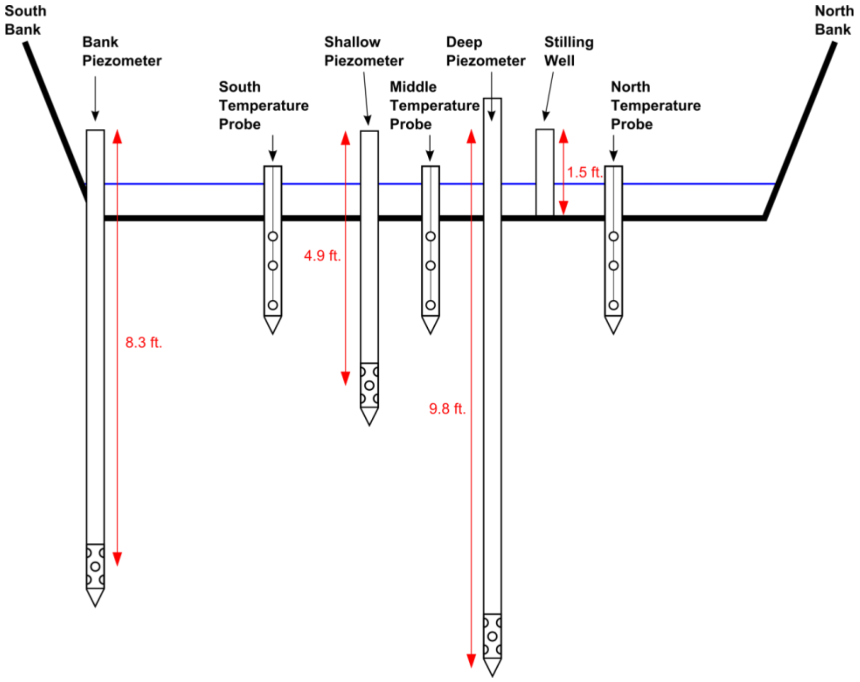

Figure 4: Cross-Section of Village East Bridge Instruments

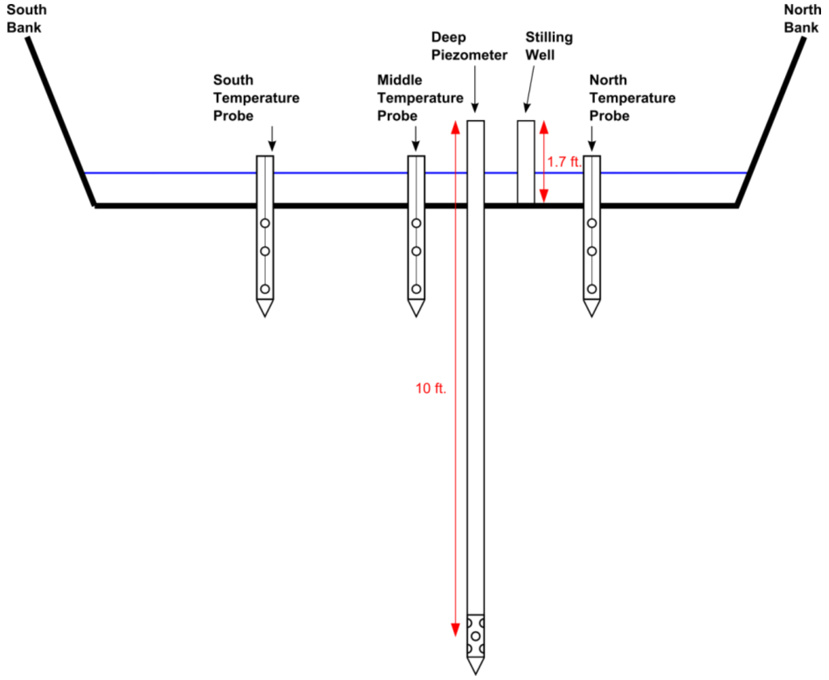

Figure 5: Cross-Section of Papoose Bridge Instruments

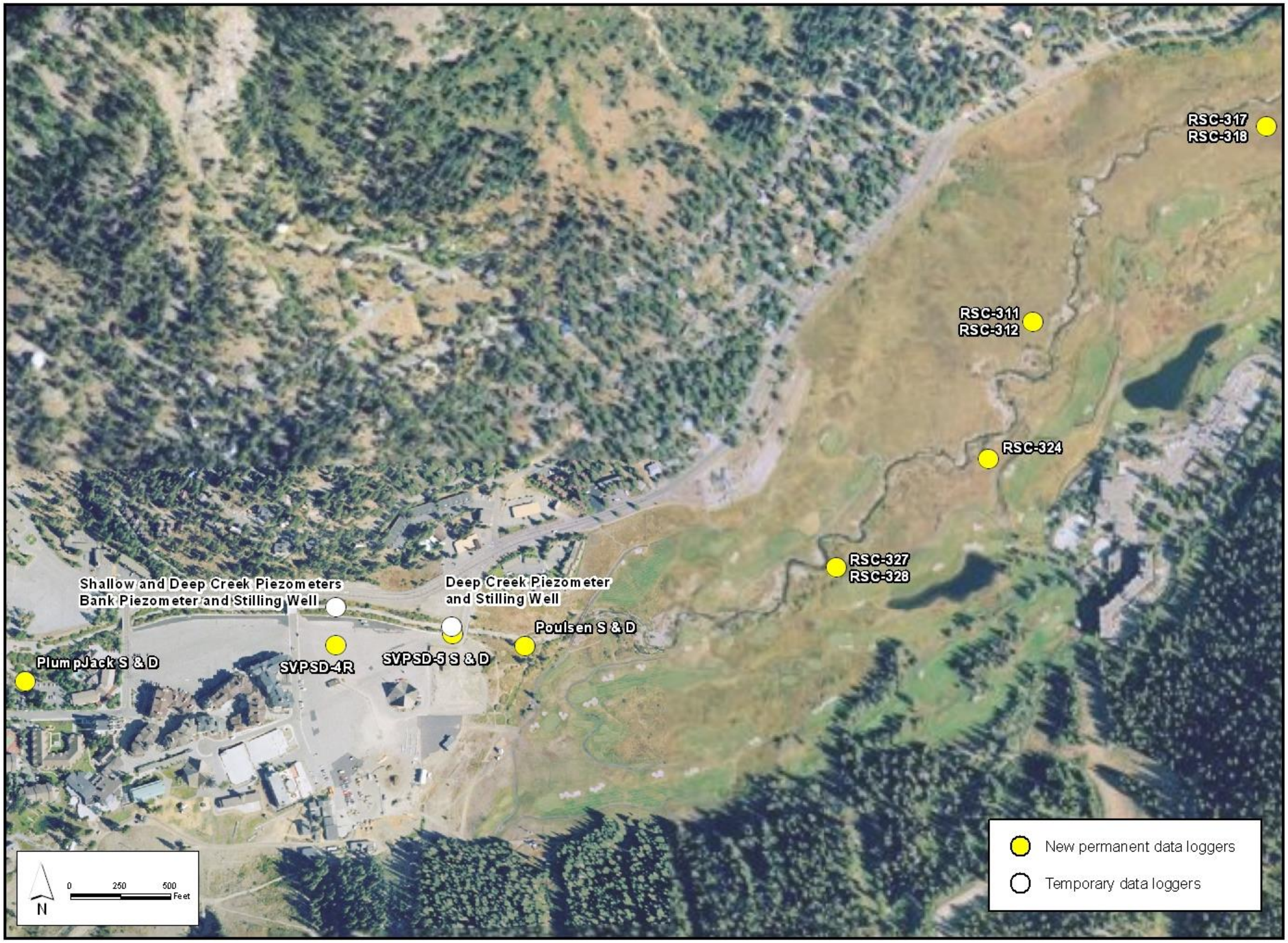

Figure 6: Data Logger Locations

2.4 AQUIFER TESTS

Two aquifer tests were conducted on well SVPSD-2. Well SVPSD-2 is representative of the municipal wells in the Western half of Olympic Valley. Results from these aquifer tests can be extrapolated to other municipal wells in the Western half of Olympic Valley. One aquifer test was conducted while Squaw Creek was flowing; and one aquifer test was conducted while Squaw Creek was dry. Comparing results from these two tests allows us to identify the influence from Squaw Creek on well pumping, and to quantify the amount of water that is captured by the pumping well from Squaw Creek.

Groundwater levels were recorded in the pumping well, six monitoring wells, and four temporary piezometers during both tests. The locations of the pumping well, monitoring wells, and piezometers are shown in Figure 7. Groundwater level data were collected with data loggers at constant five minute intervals during each test. Hand measured groundwater levels were collected at all monitoring wells as backup to the data loggers. Details of the two tests are shown on Table 1.

Table 1: Aquifer Test Details

	Test 1	Test 2
Start Time	6/23/2009 8:20 AM	9/8/2010 8:40 AM
End Time	6/25/2009 11:20 AM	9/10/2010 11:40 AM
Total Pumping Time	51 hours	51 hours
Time that Wells Were Rested Prior to Pumping	> 24 hours	> 24 hours
Amount of Recovery Data Collected	2.5 hours	2.5 hours
Flow condition in Squaw Creek	Flowing	Dry
Average Pumping Rate	316 gpm	308 gpm

Figure 7: Aquifer Test Groundwater Level Monitoring Locations

SECTION 3
PHASE II RESULTS

Activities undertaken as part of the Phase II study included:

- Analyzing water temperature data and water level data from the trapezoidal channel to quantify the amount of water flowing from Squaw Creek into and out of the shallow aquifer.
- Analyzing the aquifer test data to refine hydrogeologic parameters and calculate the amount of water a pumping well removes from Squaw Creek.
- Analyzing and documenting results of a temperature and radon study of lower Squaw Creek, conducted by Lawrence Livermore Laboratory and Cal State East Bay.
- Updating the groundwater model based on the Creek/Aquifer study, studies by Lawrence Livermore Laboratory, and other recent hydrogeologic investigations.

Full results from the Phase II studies are documented in the task 4.1 report (HydroMetrics WRI, 2013b), the task 4.2 report (HydroMetrics WRI, 2013a), the groundwater model update report (HydroMetrics WRI, 2013c), and the radon and other tracers report (Moran, 2013). These previous reports are included as appendices to this report. The following sections highlight the significant activities and results from the Phase II study.

3.1 CREEK/AQUIFER INTERACTION ANALYSIS

Temperature and water level data from the trapezoidal channel were used to quantify seasonal and long-term movement of water between Squaw Creek and the underlying groundwater system. The data provided estimate of vertical seepage velocities in and out of Squaw Creek; hydraulic gradients between Squaw Creek and the surrounding aquifer; and the vertical hydraulic conductivity of the sediments directly below Squaw Creek. These estimates can only be obtained when Squaw Creek is flowing, and the sediments beneath Squaw Creek are saturated. The sediments beneath Squaw Creek appear unsaturated between July 15, 2009 and September 29, 2009; and the analysis of seepage and vertical conductivities was not performed for this period.

The average seepage velocities from the three Village East Bridge probes are shown in Figure 8. Negative velocities equate to water flowing from Squaw Creek into the surrounding aquifer; positive velocities equate to water flowing from the surrounding aquifer into Squaw Creek. Seepage velocities were converted to volumetric flow rates measured in cubic feet per second (cfs) by applying them to a representative section of Squaw Creek, with a width of 25 feet, a length of 1000 feet, and an effective porosity of 0.30. Table 2 presents seepage velocities and flow rates into and out of Squaw Creek near the Village East Bridge site for the periods before and after the probes appeared dry.

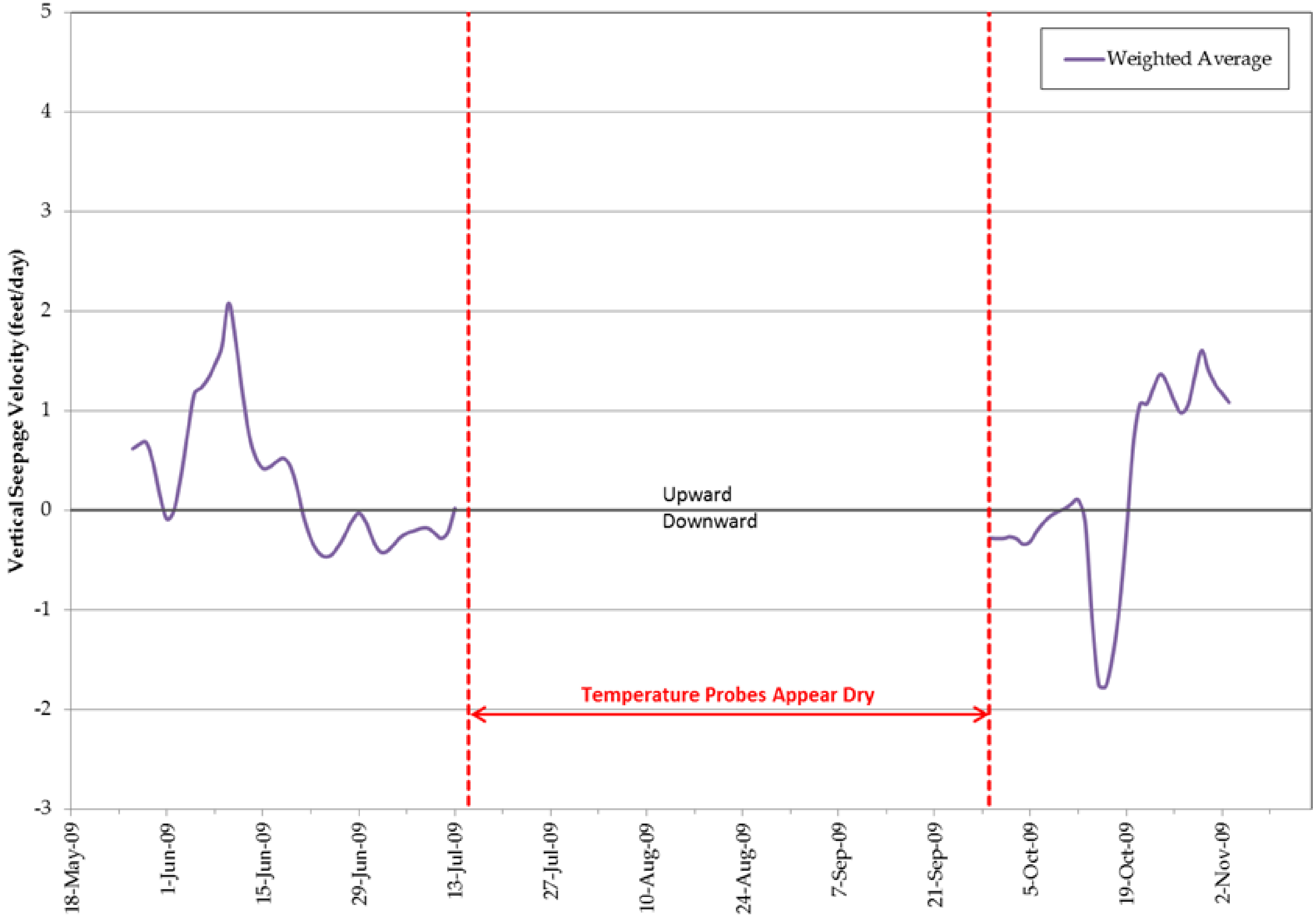

Figure 8: Village East Bridge Temperature Probes Average Seepage Velocities

Table 2: Summary of Village East Bridge Seepage Rates

Analysis Period	Statistic	Seepage Velocity (ft./day)	Flow Rate of 25ft x 1000ft Reach (cfs)	Date
Before Probes Appear Dry	Maximum Downward	-0.47	-0.041	6/24/2009
	Maximum Upward	2.08	0.180	6/10/2009
	Average	0.28	0.024	
After Probes Appear Dry	Maximum Downward	-1.77	-0.154	10/16/2009
	Maximum Upward	1.60	0.139	10/30/2009
	Average	0.23	0.020	

The average seepage velocities from the three Papoose Bridge probes are shown in Figure 8. Negative velocities equate to water flowing from Squaw Creek into the surrounding aquifer; positive velocities equate to water flowing from the surrounding aquifer into Squaw Creek. Seepage velocities were converted to volumetric flow rates (in cfs) by applying them to a representative section of Squaw Creek, with a width of 25 feet, a length of 1000 feet, and an effective porosity of 0.30. Table 3 presents seepage velocities and flow rates into and out of Squaw Creek near the Papoose Bridge site for the periods before and after the probes appeared dry.

Table 3: Summary of Papoose Bridge Seepage Results

Analysis Period	Statistic	Seepage Velocity (ft./day)	Flow Rate of 25ft x 1000ft Reach (cfs)	Date
Before Probes Appear Dry	Maximum Downward	-3.07	-0.267	5/28/2009
	Minimum Downward	-0.34	-0.029	6/23/2009
	Average	-1.03	-0.089	
After Probes Appear Dry	Maximum Downward	-2.46	-0.213	10/16/2009
	Minimum Downward	-0.56	-0.048	10/24/2009
	Average	-1.11	-0.097	

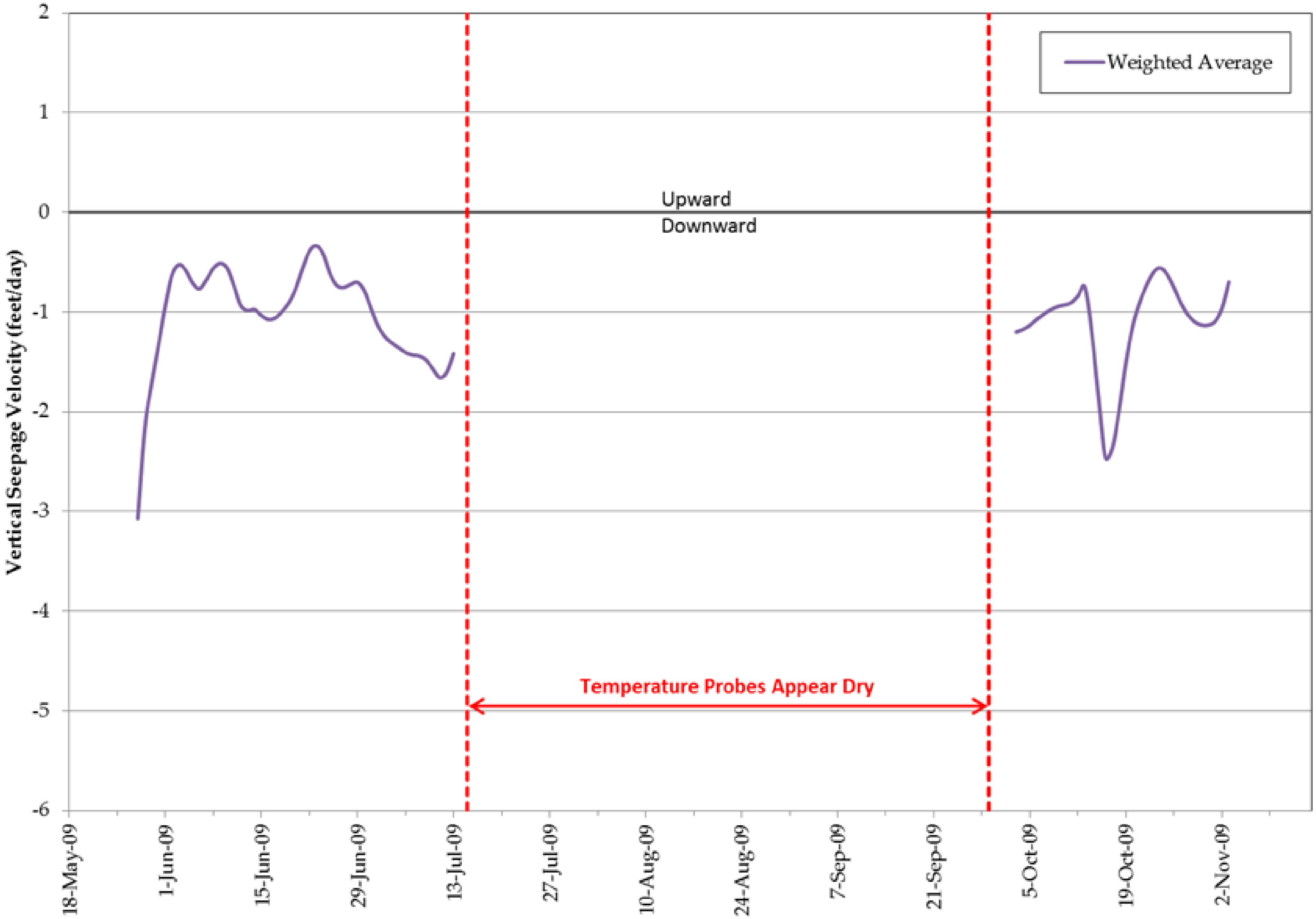

Figure 9: Papoose Bridge Temperature Probes Average Seepage Velocities

Figure 8, Figure 9, Table 2, and Table 3 show only average results. Inspection of results from individual seepage probes show that seepage can vary significantly across the trapezoidal channel. In particular, the probes nearest Squaw Valley Road often demonstrate inflow to Squaw Creek at the same time that probes farthest from Squaw Valley Road demonstrate outflow from Squaw Creek. The data suggest a complex Creek/Aquifer interaction that is shown on Figure 10. Key components of this Creek/Aquifer interaction include:

- Mountain-front recharge raises groundwater elevations north of Squaw Creek, near Squaw Valley Road.
- The groundwater north of Squaw Creek discharges into Squaw Creek, increasing Squaw Creek flows.
- Near the middle of Squaw Creek, water begins to discharge from Squaw Creek into the aquifer. The Creek discharge is less than the recharge from the north side of Squaw Creek.
- Discharge from Squaw Creek recharges the shallow aquifer below Squaw Creek, but does not control groundwater elevations in deeper aquifers. Groundwater elevation data suggest that the aquifer just ten feet below the base of Squaw Creek is influenced by recharge from the edges of Olympic Valley

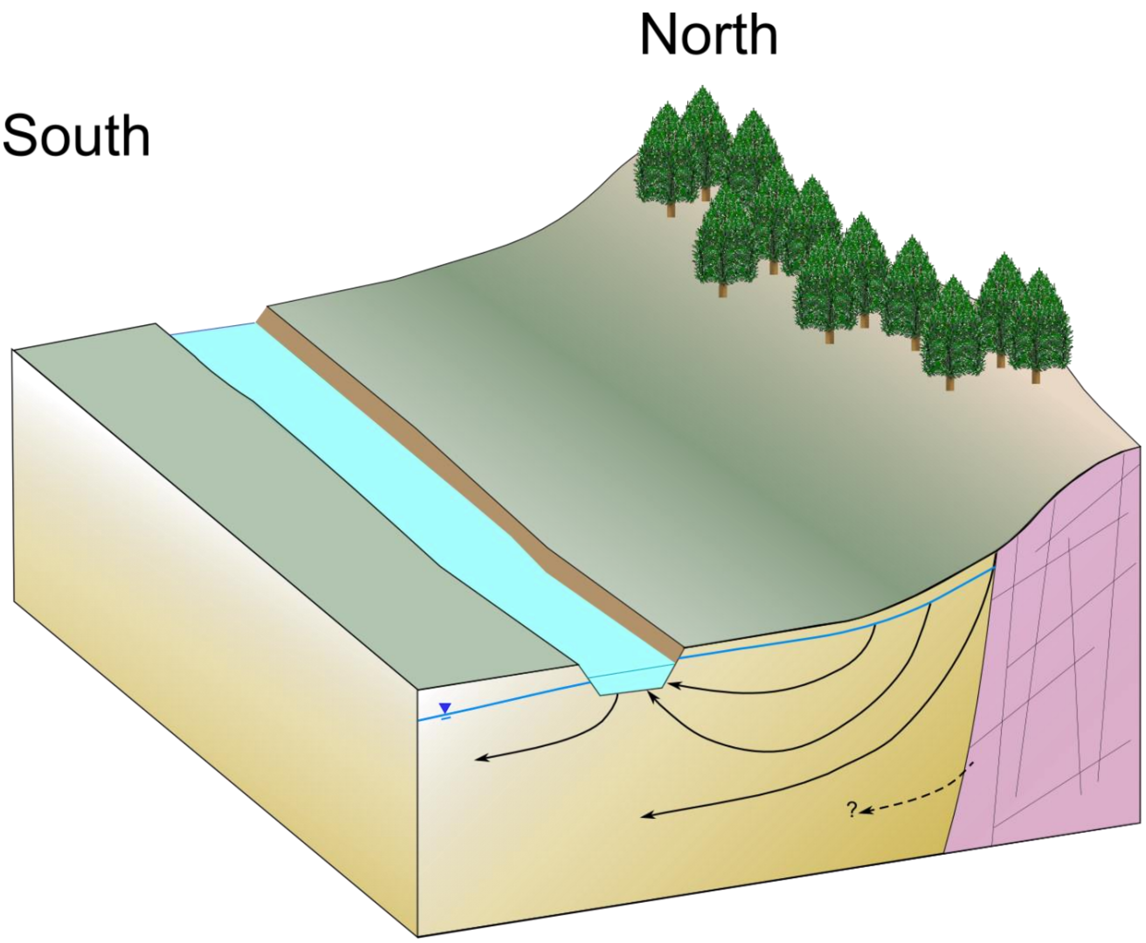

Figure 10: Conceptual Diagram of Stream/Aquifer Interaction during Late Spring and Early Summer

As shown on Table 2 and Table 3, the maximum measured flows into and out of Squaw Creek are less than 0.3 cfs for a 1000 foot section of trapezoidal channel. This provides guidance on when creek losses become a significant impact on creek flows. For example, when Squaw Creek flows are above 3 cfs, creek losses likely account for less than 10% of the total flow. In 2009, when the Phase I study was conducted, creek flows dropped to 3 cfs in mid to late July.

The Squaw Creek temperature and water level show that the Creek is preferentially recharged near the Village East Bridge in spring and early summer. Conversely, interactions near Papoose Bridge are dominated by outflow from the Creek to the aquifer. This is counterintuitive, as the Creek is expected to be recharged more as it approaches the meadow.

3.2 AQUIFER TEST ANALYSIS

Two aquifer tests were conducted: one while Squaw Creek was flowing and one while one Creek was dry. The first test was conducted between June 23 and June 25, 2009. The second test was conducted between September 8 and September 10, 2010.

3.2.1 AQUIFER PARAMETERS

Aquifer tests are commonly analyzed to produce estimates of aquifer parameters such as hydraulic conductivity and storativity. Aquifer parameters are more accurate when the test is not influenced by surrounding pumping or recharge. The 2010 test was conducted while Squaw Creek was dry, and therefore this test had the lease influence from outside recharge. Therefore, the aquifer parameters calculated from the 2010 test are likely the most reliable parameters.

Results from the 2010 test suggest a hydraulic conductivity of 235 feet per day, and a storativity of 0.096. The hydraulic conductivity is high, and is indicative of an aquifer consisting of coarse sands and gravels. We could not determine if the high hydraulic conductivity was influenced by groundwater leaking in through bedrock fractures – which would raise the hydraulic conductivity.

3.2.2 STREAMFLOW DEPLETION FROM PUMPING

Combining the data from the two aquifer tests with information gleaned from the creek temperature analysis allow us to estimate the amount of depletion in Squaw Creek's flow due to pumping. The depletion estimates require values of aquifer transmissivity and storage coefficient, as well as streambed conductivity, and streambed depth. The transmissivity and storage coefficient values used were those estimated from the results of the 2010 aquifer test. The streambed conductivity and streambed depth were estimated from results of the temperature analysis.

Streamflow depletion due to pumping changes over time. When a well is first turned on it pumps water out of the aquifer immediately adjacent to the well. As pumping continues, the well draws water from farther away. Therefore, we expect creek depletion to be small initially, and grow over time.

Figure 11 shows the streamflow depletion curve that was calculated for well SVPSD#2 using the Hundt solution for stream depletion (Hundt, 1999). Time since pumping began is plotted on the X-axis. The percentage of pumping that is derived from the stream is plotted on the Y-axis. The two sets of red dashed lines on Figure 11 show the amount of flow captured from Squaw Creek by well SVPSD#2 after eight hours of pumping and at the end of Test 1. Eight hours of pumping was chosen to represent average pumping conditions.

Figure 11 shows that at the end of the 2009 aquifer test, after 51 hours of pumping, well SVPSD#2 captured approximately 21.5% of its total discharge from Squaw Creek. Assuming an average pumping rate of 316 gpm, the well was depleting streamflow by approximately 68 gpm, or 0.15 cubic feet per second (cfs). The average creek total Creek flow summed from the South Fork and Shirley Canyon stream gauges during Test 1 was 30.25 cfs. Therefore, well SVPSD#2 captured a maximum of one-half of one percent of Squaw Creek's flow during Test 1.

Figure 11 additionally shows that during an eight hour pumping cycle, well SVPSD#2 captures an average of 1.12% of its total discharge from Squaw Creek. Assuming an average pumping rate of 300 gpm, well SVPSD#2 captures an average of 3.4 gpm, or less than 0.008 cfs during a customary 8-hour pumping cycle. The 8-hour pumping cycle represents a situation when a well may be on for eight hours, then rested for 16 hours. This cycle is reasonable when reviewing District pumping data. For example, in July of 2012, well SVPSD#2 pumped enough water to be operating approximately 7.5 hours per day each day of the month.

Well SVPSD#2 is not the only well that causes streamflow depletion. The aquifer parameters estimated from the well SVPSD#2 aquifer tests can be combined in the Hundt solution with average pumping rates and well locations to obtain similar creek depletion estimates for each active SVPSD well. Table 4 shows the estimated amount of water captured from Squaw Creek in eight hours by each well. The total amount of water captured by any one well over an 8-hour period was calculated by summing the estimated capture from each 15-minute interval of the pumping period.

Table 4: 8-Hour Creek Capture from Active SVPSD Wells

SVPSD Well	Distance from Squaw Creek (Feet)	Average Pumping Rate (gpm)	8-hour pumping total (gallons)	Estimated 8-hour Squaw Creek Capture (gallons)	Percent of pumping captured from Creek in 8 hours
SVPSD-1R	584.3	391	187,680	355	0.19%
SVPSD-2	350	317	152,160	1,702	1.12%
SVPSD-3	276	101	48,480	893	1.84%
SVPSD-5R	121	419	201,120	9,659	4.80%

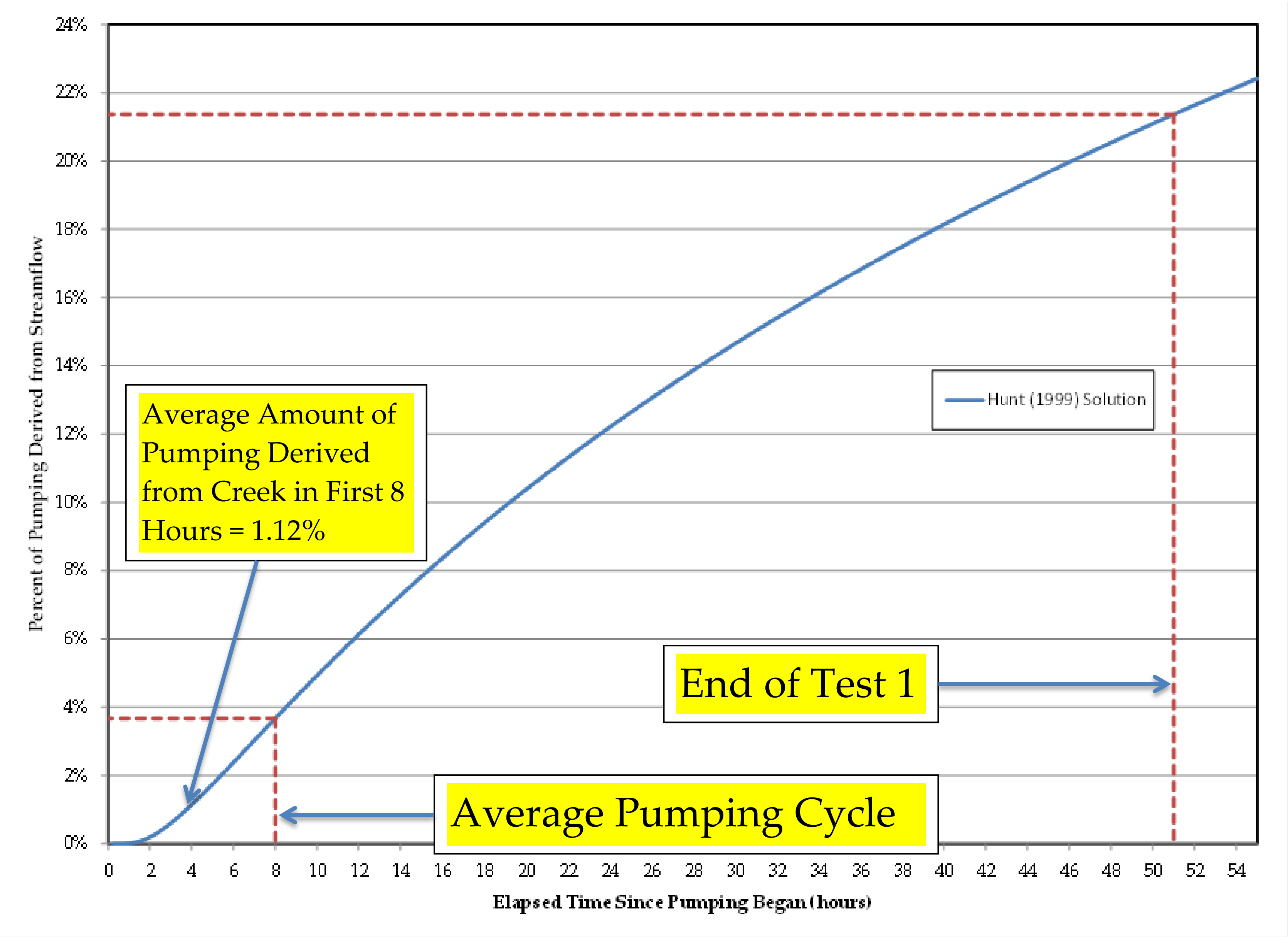

Figure 11: Streamflow Depletion Curve for Well SVPSD#2

SVPSD further provided the total amount of water pumped by each well for every month during water years 2012 and 2013. Total monthly pumping was converted to an estimated number of days pumped, using the pumping rates in Table 4. For example, well SVPSD#1R pumped 2,107,000 gallons in January, 2012. This equates to 11.23 days of pumping if the well pumps for eight hours per day at 391 gpm. Table 4 furthermore shows that well SVPSD#1R would extract 3,987 gallons of water from Squaw Creek in those 11.23 days of pumping, or an average of 128 gallons per day (for each of the 31 days in January).

The total streamflow depletion from pumping the four active SVPSD wells ranged between 0.005 cfs and 0.017cfs for water years 2012 and 2013. Total streamflow depletion in both 2012 and 2013 was approximately 2.5 million gallons, or slightly more than twice the size of the District's West Tank. Comparing the total well depletion estimates to daily streamflow measurements allows us to estimate the percentage of streamflow captured by the SVPSD wells. Figure 12 and Figure 13 graphically show the interaction between Squaw Creek flows and SVPSD pumping. The red line on each figure shows the measured flow entering Squaw Creek in cfs, and is related to the axis on the right side of the graph. The blue line on each figure shows that percentage of measured creek flow that is captured by SVPSD pumping. No creek flow is captured by pumping when the trapezoidal channel is dry, and the maximum capture was set to 100% of creek flow.

The total streamflow depletion from pumping is below 0.2 cfs, and streamflows in 2012 and 2013 were up to nearly 180 cfs. Therefore, wells only capture a significant percentage of streamflow in very low-flow periods. During most times, wells capture one percent or less of streamflow. In water year 2012, wells captured one percent or less of measured streamflow in 337 of the 365 days. In water year 2013, wells captured one percent or less of measured streamflow in 348 of 365 days.

Wells captured more than one percent of streamflow for only three days in July of 2012, and for only seven days in July of 2013. Therefore, SVPSD pumping may cause the trapezoidal channel to dry out between three and seven days earlier than it would with no pumping. The single days of significant streamflow capture during August on both Figure 12 and Figure 13 appear to be artifacts of errors in streamflow measurement, and it is unlikely that pumping had any influence on creek flows on these days.

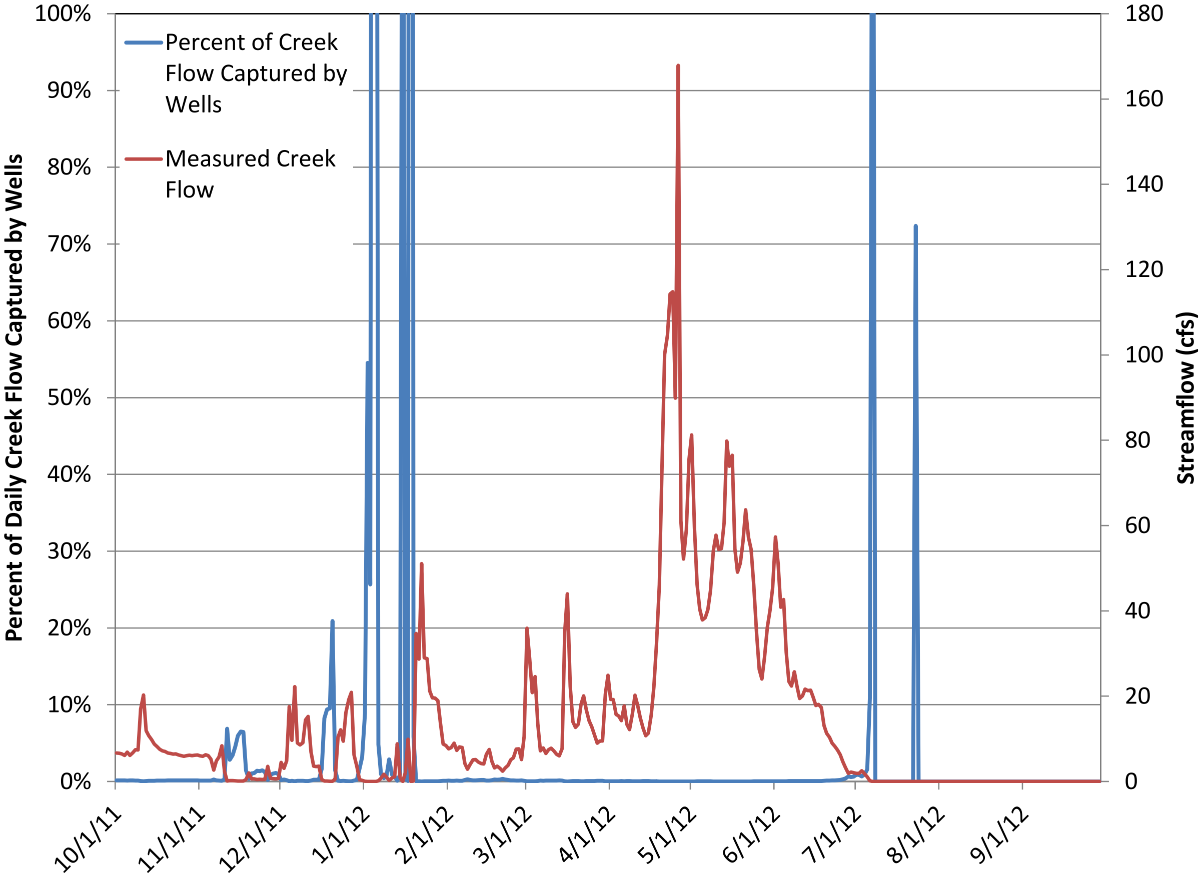

Figure 12: Streamflow Capture by SVPSD Wells in Water Year 2012

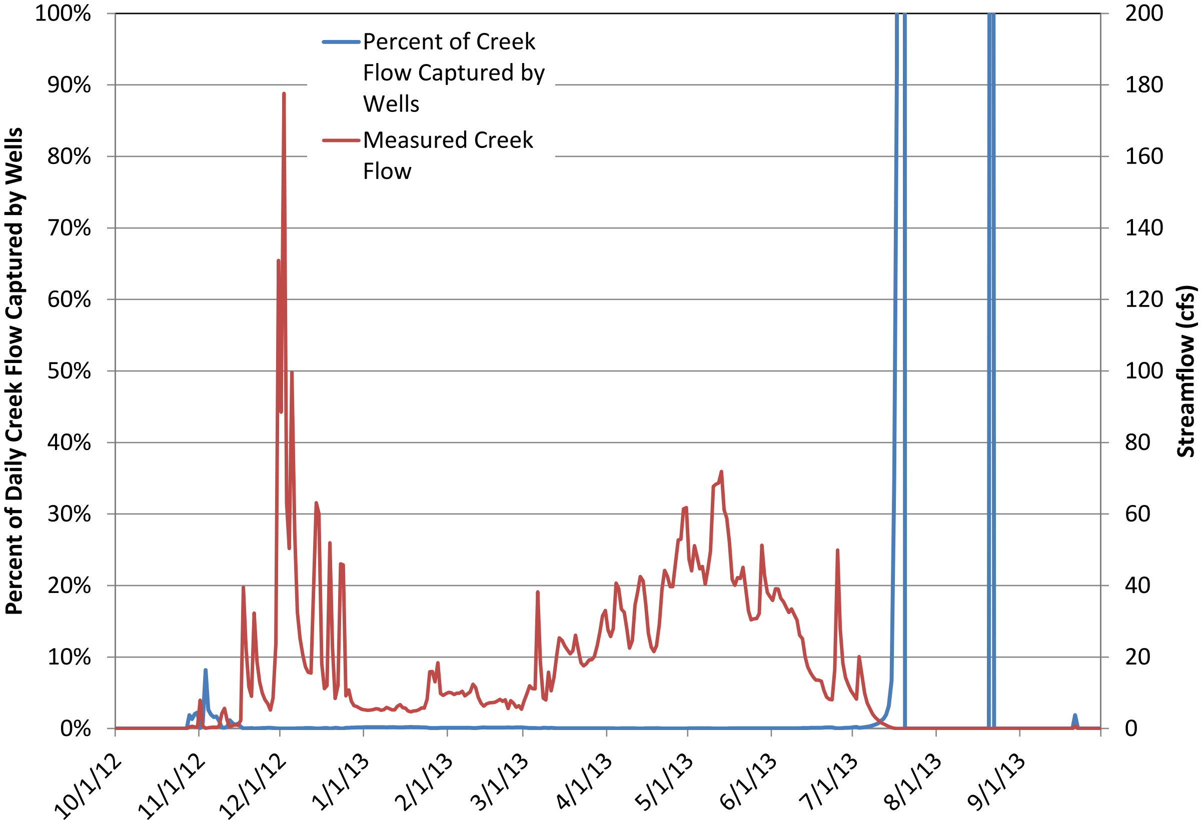

Figure 13: Streamflow Capture by SVPSD Wells in Water Year 2013

Table 5 shows the number of days during water year 2012 and 2013 that SVPSD pumping captured various amounts of streamflow. The data in Table 5 include both winter and summer flows.

Table 5: Number of Days Streamflow is Captured by SVPSD Pumping

		Water Year	
		2012	2013
Percentage of Streamflow Captured by Pumping	0 to 1 %	337	348
	2 to 5 %	9	10
	6 to 10%	9	2
	11 to 25%	2	0
	26 to 50%	1	1
	51 to 75%	2	0
	76 to 100%	5	4

The same pumping and streamflow capture calculations show that approximately 2% of SVPSD's total pumping is derived from reduced streamflow. This number does not account for groundwater that may be flowing towards the trapezoidal channel, but is intercepted by wells before it gets there.

3.3 LOWER SQUAW CREEK RADON AND TEMPERATURE STUDY

The interaction between Squaw Creek and the shallow aquifer was further informed by a study conducted by Lawrence Livermore National Laboratory (LLNL) and California State University East Bay (CSUEB). Dr. Jean Moran and her colleagues conducted a number of tests on Squaw Creek both in the trapezoidal channel and in the meadow to identify locations or reaches along Squaw Creek where groundwater enters the stream, and to quantify groundwater influx to the stream. The research was part of a larger study aimed at investigating the vulnerability of groundwater and stream baseflow to predicted future climate change. The main geochemical tool used in the study goals was radon, a naturally-occurring dissolved gas isotope found in surface water only in proximity to groundwater inputs. Ancillary data used to examine stream-groundwater interaction included stable isotopes of hydrogen and oxygen, and heat, as recorded using Distributed Temperature Sensing.

3.3.1 RADON STUDY

Radon activity was measured along a 1 km reach of Squaw Creek at 20 m intervals in two sampling surveys. A simple mass balance model of stream radon activity was developed that considered only groundwater discharge as a radon source, and gas emanation as a radon sink. Radon activity was measured in both the trapezoidal channel and meadow portions of Squaw Creek. The radon surveys were conducted in June and July of 2009.

Radon data suggested that groundwater discharge in the meadow constitutes about 5% of total stream discharge in early June, 2009 (near the peak of the hydrograph during spring snowmelt) and about 18% of total discharge in early July, 2009. By late July and August, groundwater inflow makes up nearly all of the observed flow in the meadow portion of Squaw Creek.

3.3.2 DISTRIBUTED TEMPERATURE SENSING (DTS)

Distributed temperature sensing (DTS) can yield spatially refined estimates of relatively modest groundwater inflow even in large rivers. DTS uses the properties of a fiber optic cable to measure temperature. The fiber optic cable serves as the thermometer, with a laser serving as the illumination source. Measurements of temperature every 1 meter along the cable are resolved every 1 to 2 minutes, with an uncertainty of about 0.2°C.

The University of Nevada at Reno deployed a one kilometer long distributed temperature sensing apparatus in Squaw Creek on July 1 and July 2, 2009 over a one kilometer reach beginning at the Papoose Bridge downstream of the trapezoidal channel. The location of the DTS cable is shown on Figure 14.

Change in temperature over the length of the DTS cable is shown for two time periods on Figure 15. Both sets of data show a gradual increase in the stream temperature with distance downstream. The groundwater influx, at slightly higher temperature than stream water, results in a slight warming of stream water. The nighttime data show where two tributaries, one near the beginning of the study reach and one near the end, result in warm and cool deflections from the overall gradually increasing trend, respectively. The lack of any other significant deviations from the overall gradual increase indicates that groundwater influx is not focused at discrete locations, but rather is distributed evenly along the study reach. Similarly, lack of evidence for localized influx at locations where faults cross the stream suggests that if faults are a conduit for groundwater flow, the flow is not a significant component of the discharge carried by the stream.

3.3.3 STABLE ISOTOPES IN GROUNDWATER AND SQUAW CREEK

Stable isotopes of hydrogen and oxygen were used to examine sources of water to Squaw Creek. The minor stable isotopes of water molecules including ^{2}H deuterium (D) and ^{18}O oxygen vary as a function of temperature, elevation, and latitude. In general, the lighter isotopes of hydrogen and oxygen are concentrated in precipitation formed in colder air masses at higher elevations, compared to precipitation formed in warmer air masses at lower elevations. In Olympic Valley, snowmelt runoff from the top of the watershed is therefore expected to have a significantly lighter isotopic signature than runoff from lower elevation snow.

Overall, the range in oxygen and hydrogen isotope ratios observed in all Olympic Valley groundwater samples is consistent with water derived from precipitation. Three snow samples were collected from the top of the ski runs, High Camp, and in the meadow. Most analyzed surface water and groundwater samples showed isotopes indicative of areas between the High Camp and meadow values, indicating that most water is derived from the lower slopes and valley area.

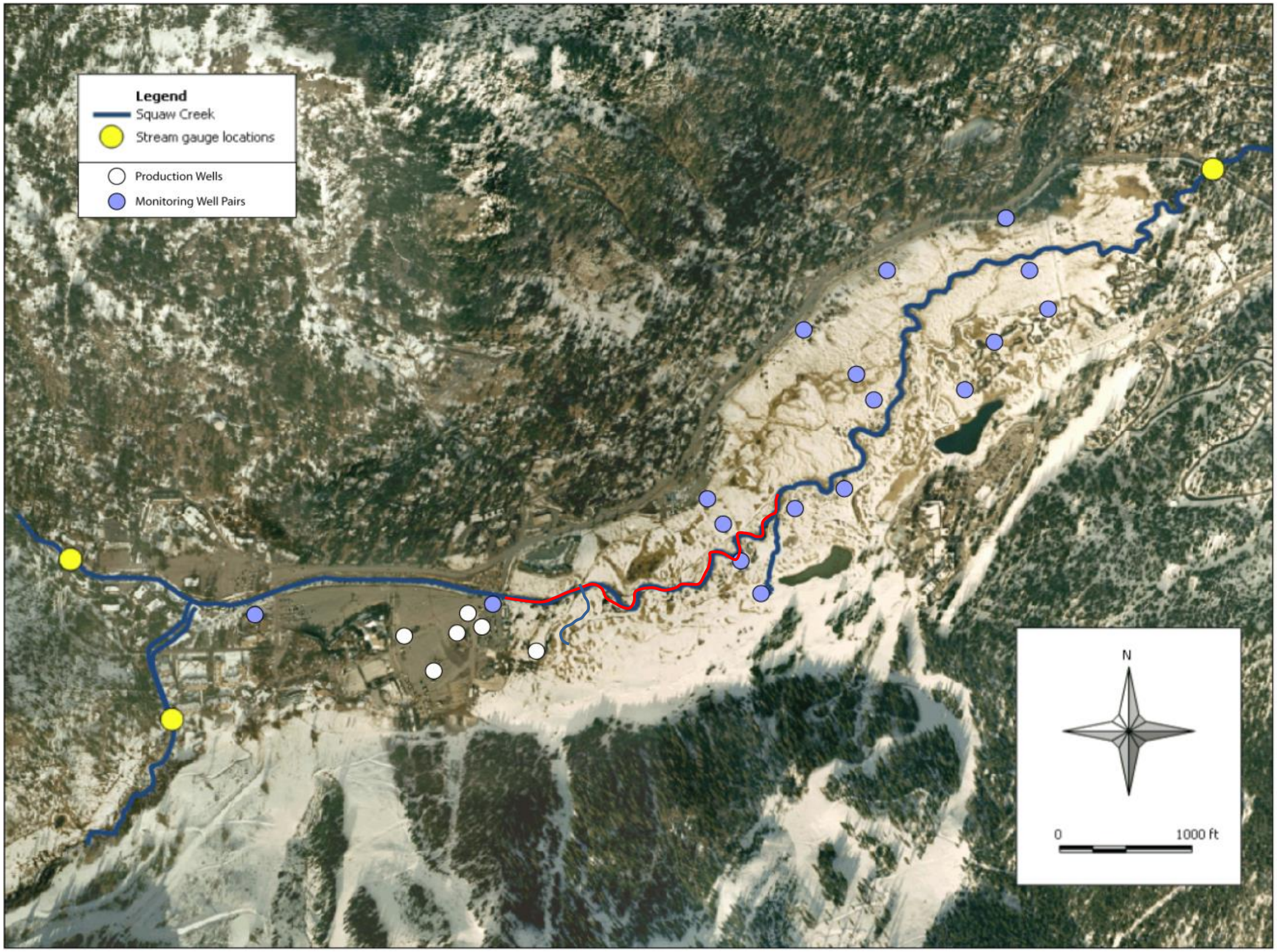

Figure 14: Distributed Temperature Sensor Location

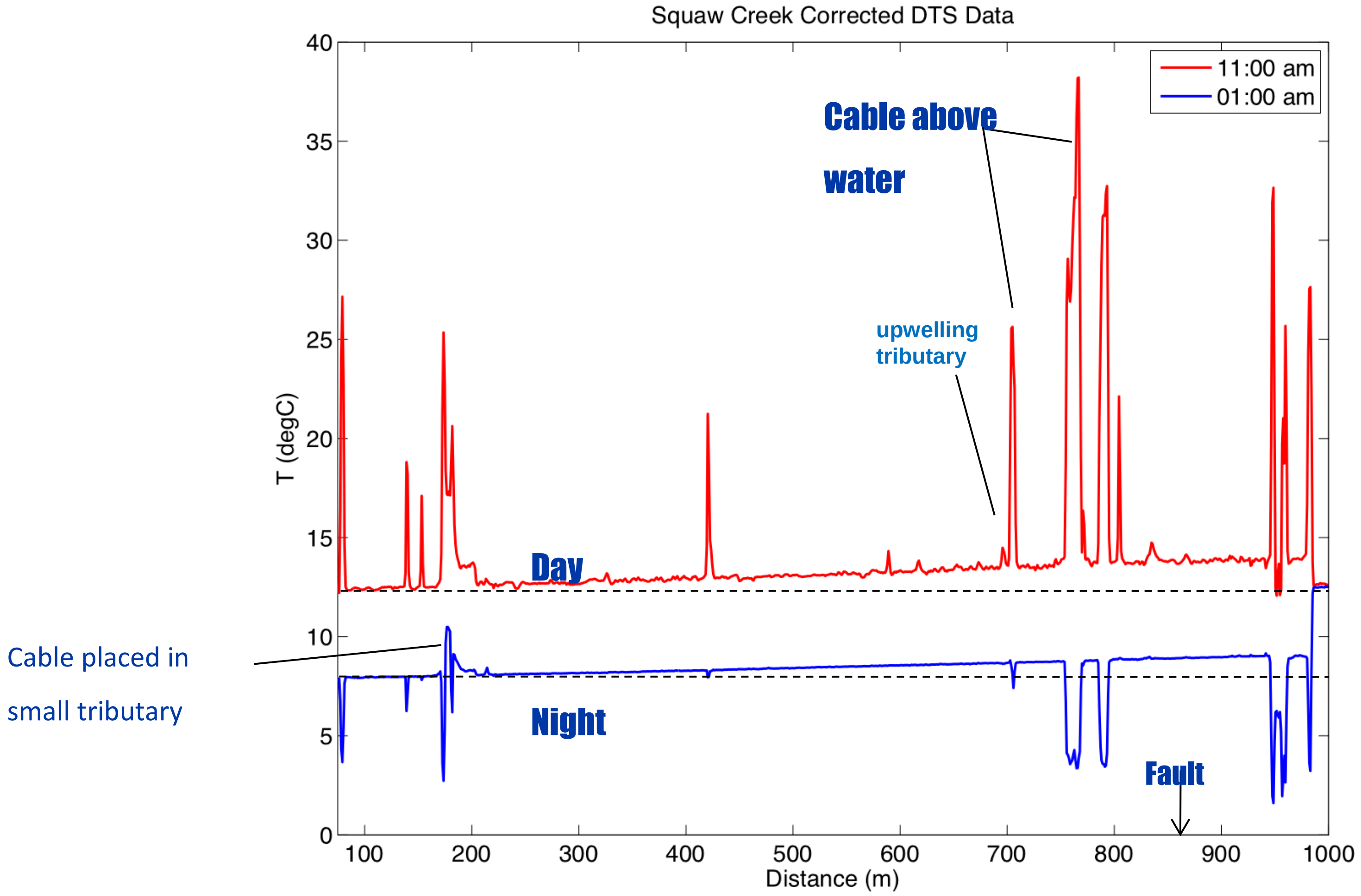

Figure 15: Example DTS Temperature Data for Squaw Creek in the Meadow

During August, 2008, when water in the Creek was dominated by baseflow, several samples were collected at the downstream gauge station near Squaw Valley Road. These samples were relatively abundant in heavier oxygen isotopes, which is evidence of evaporation. Two other samples, collected in cool pools upstream from the stream gauge location at the same time, had isotopic values that showed no evidence for evaporation. This pattern indicates that some late season pools near the downstream gauge are standing water that is evaporating, while the upstream pools that were sampled are continually fed by groundwater influx.

3.4 GROUNDWATER MODEL UPDATE

The existing Squaw Valley groundwater model was updated to incorporate recently collected data on creek/aquifer interactions, and to verify that the model accurately represents the impact of pumping on Squaw Creek. The model was extended from its previous time frame of 1992 through 2004 to simulate conditions between 1992 and 2011. The model was calibrated to match observed water levels over that time frame in both production wells and monitoring wells. An additional analysis was undertaken during calibration to match the simulated stream/aquifer interactions with data collected from two recent studies of Squaw Creek.

The updated model included and incorporated data and results produced as part of the Squaw Valley creek/aquifer study. Additionally, the model was modified to reflect the geology and hydrogeology encountered in test wells drilled by Todd Engineers for Squaw Valley Real Estate (Todd Engineers, 2013). The basin depth was modified based on results of the Todd Engineers drilling, and hydraulic properties measured from aquifer tests by Todd Engineers were incorporated into the model.

The updated and recalibrated groundwater model accurately simulates groundwater levels in Squaw Valley, and matches the measured flows between Squaw Creek and the underlying aquifer quite well. In general, the model simulates groundwater levels and the creek/aquifer interaction in the western portion of Squaw Valley better than the eastern portion. This is consistent with the model objectives of providing a tool for managing groundwater pumping in the western portion of Squaw Valley.

As part of the calibration, simulated water flow into and out of the aquifer through the streambed was compared to estimates from the temperature probe studies and the radon measurements. Figure 16 compares the modeled seasonal behavior of streambed seepage to field measurements. The vertical axis shows the rate of streambed seepage in feet per day, with positive numbers signifying inflow from the aquifer to the stream and negative numbers signifying seepage loss from the stream to the aquifer. The green bars show the range of inflow rates measured in 2009. The blue line represents the modeled average monthly seepage in the trapezoidal channel. The simulated seepage represented by the blue line lies within the range of the measured seepages, shown by the green bars. This shows that the simulated seepage rates compare well to rates measured during the May to June period and the October to November period.

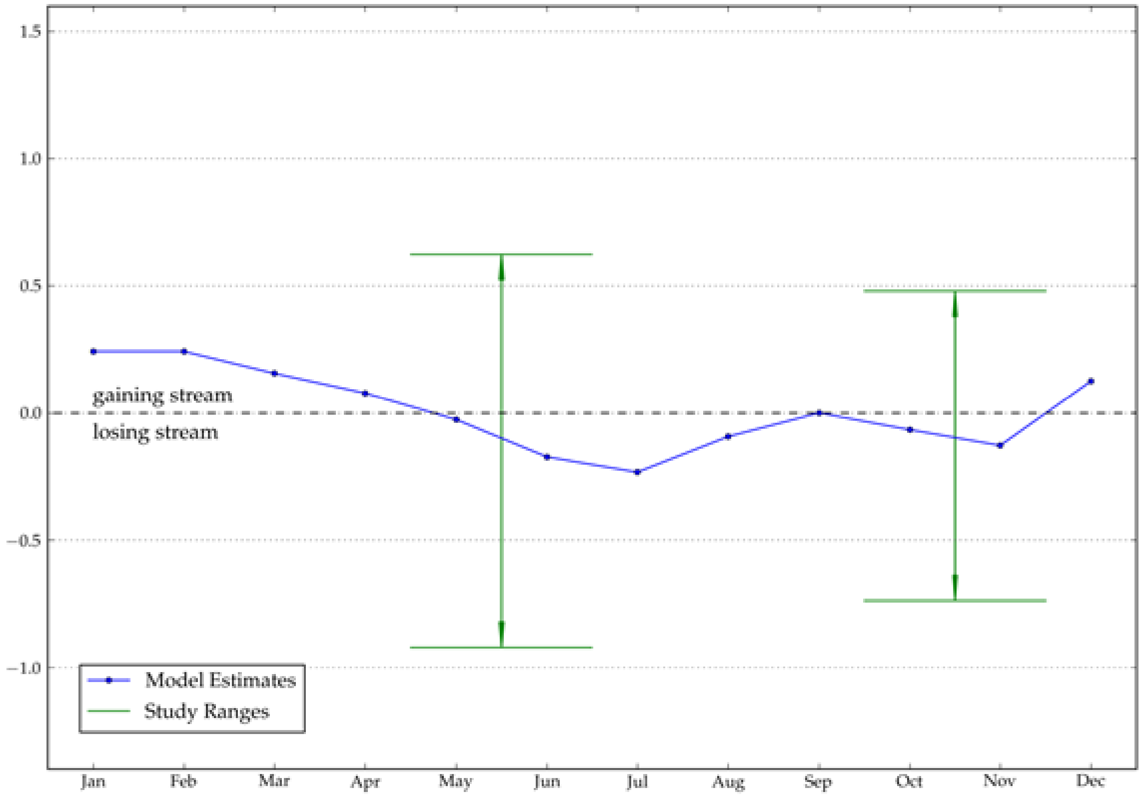

Figure 16: Comparison of Modeled and Measured Rates of Streambed Seepage for the Trapezoidal Channel Segment of Squaw Creek

Figure 17 compares simulated upward streambed seepage in the meadow to the field measurements collected by Dr. Jean Moran. The vertical axis shows the rate of streambed seepage in feet per day. The blue line represents the average monthly simulated seepage in the meadow. The green bars between May and June show the range of inflow rates that were measured in the field.

The simulated Squaw Creek inflow values in the meadow are below the range of measured values throughout the entire season. This is likely because the model cannot recreate some of the very high water levels observed beneath the meadow. As a result, the upward gradients simulated by the model in this region are not as strong as those that are likely to exist in the real aquifer. The model's underestimation of upward gradients in the meadow is likely the cause of its corresponding underestimation of seepage rates into Squaw Creek.

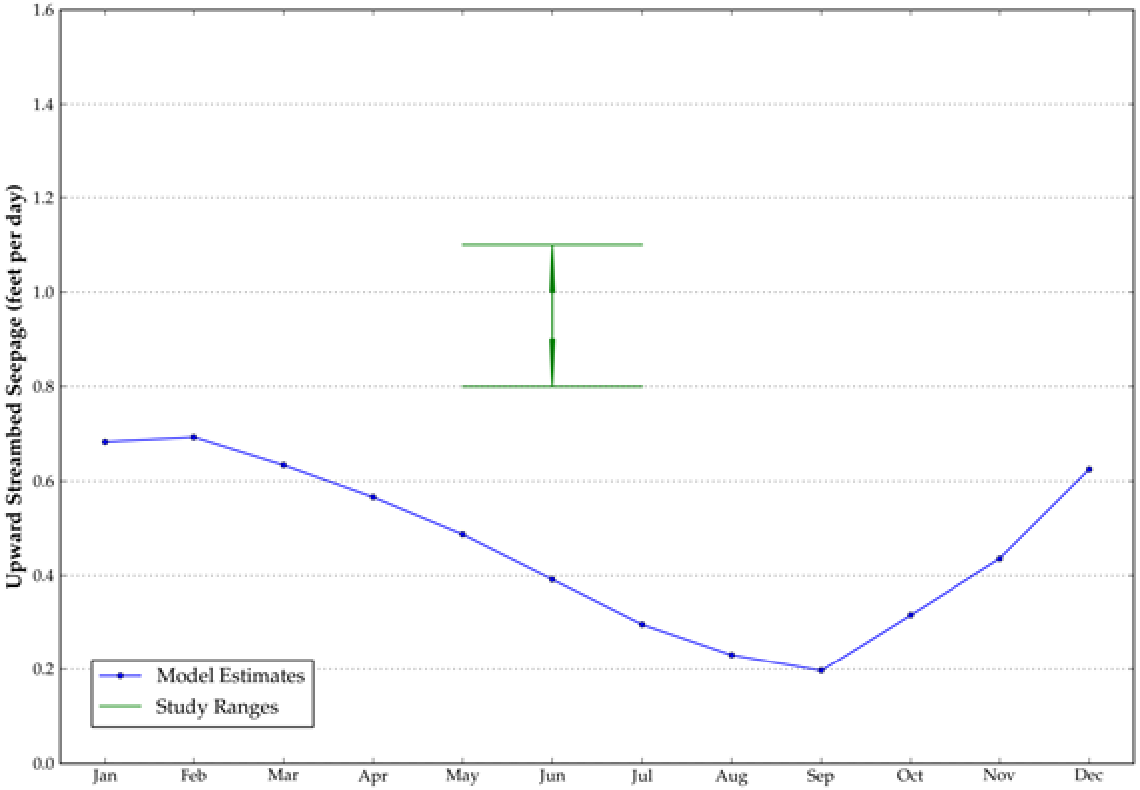

Figure 17: Comparison of Modeled and Measured Rates of Upward Streambed Seepage for the Meadow Segment of Squaw Creek

SECTION 4
CONCLUSIONS

The following conclusions are based on results of the studies completed and reviewed as part of the Creek/Aquifer interaction study.

4.1 WEST OLYMPIC VALLEY

West Olympic Valley is the area west of Papoose Bridge. The trapezoidal channel runs through West Olympic Valley. The majority of current, non-irrigation, municipal pumping occurs in West Olympic Valley. Creek/aquifer interactions in West Olympic Valley can be generally divided into three time frames: winter through early summer, mid-summer, and late summer through fall.

4.1.1 WINTER THROUGH EARLY SUMMER CREEK/AQUIFER INTERACTIONS

This time period is characterized by relatively high flows in Squaw Creek. Squaw Creek may fill the trapezoidal channel from bank to bank, or may simply cover a significant portion of the creek bed. Squaw Creek is fed by rainfall and snowmelt during this period. Groundwater levels in West Olympic Valley are high during this period; generally at or above the elevation of the creek bed.

The trapezoidal channel drains water from the shallow aquifer during this period. Measurements suggest that the trapezoidal channel drains up to 0.18 CFS for every 1000 feet of channel. This is approximately equal to 80 gallons per minute for every 1000 feet of channel.

Municipal pumping during this period directly removes little or no water from the trapezoidal channel. Water pumped by municipal wells during this period intercepts groundwater that might otherwise flow to the trapezoidal channel. This is supported by the facts that the trapezoidal channel is gaining water, rather than losing water, during this period. Additionally, carbon isotope data presented by Singleton and Moran (2010) indicate that water pumped by the municipal wells percolated through a vegetated zone rather than infiltrated through the Creek bed; suggesting the groundwater percolated along the margins of the Valley. The amount of water intercepted by municipal wells is only a small fraction of the total creek flow in this time period.

Stable isotope data presented by Singleton et al. (2008) suggest water pumped by municipal wells during this period is relatively young; often less than one year old. Noble gas recharge temperature data from the same report suggest that the water pumped by municipal wells recharged the basin just above the Valley floor. While these data reflect a range of recharge elevations, the average recharge elevation is approximately 6350 feet.

Based on these conclusions, the conceptual model of water flow in West Olympic Valley during spring and early summer starts with groundwater recharging the aquifer along the basin margins. This groundwater flows both from west to east towards the meadow, and towards the trapezoidal channel from both north and south edges of the basin. The trapezoidal channel drains the shallow aquifer along both its north and south banks, although more water appears to flow into the trapezoidal channel from the north bank. This is likely due to municipal pumping south of the trapezoidal channel. Wells intercept some of the basin recharge that would otherwise discharge to the trapezoidal channel. The amount of water intercepted by the wells is small compared to the flow in the trapezoidal channel. The majority of flow in the trapezoidal channel, and in Squaw Creek, is derived from snowmelt and rainfall.

4.1.2 MID-SUMMER CREEK/AQUIFER INTERACTIONS

This period is characterized by relatively low Creek flows. No standard flow has been set to differentiate between early summer and mid-summer flows. It may be necessary to set a flow standard that differentiates between early summer and mid-summer flows when pumping strategies are developed because pumping strategies during high creek flow periods will likely differ from pumping strategies during low creek flow periods. For discussion purposes, we can assume that mid-summer flows are generally less than 10 cfs. This period represents the very end of the annual snowmelt. At the end of this period, snowmelt ceases and there are no more surface water flows feeding the two western branches of Squaw Creek. This period likely lasts between a few weeks and a month.

During this time period, the trapezoidal channel goes from generally gaining water to generally losing water. Similarly, municipal wells in West Olympic Valley go from intercepting water before it reaches the trapezoidal channel, to drawing water out of the trapezoidal channel. The amount of water drawn from the trapezoidal channel is a small percentage of the total pumping. After eight hours of pumping, well SVPSD-2R extracts only 4% of its water from the trapezoidal channel. As flows in Squaw Creek decline, however, this small amount of capture represents a greater and greater percentage of the total Creek flow.

The trapezoidal channel apparently loses more water at the eastern end of the channel than near the middle of the channel. This is supported by the temperature data, as well as geochemical data from wells SVPSD-5S and SVPSD-5D (Moran, personal communication). Unlike all other wells, groundwater sampled from wells SVPSD-5S and SVPSD-5D suggest the water was derived from Squaw Creek and not the basin boundaries.

During the mid-summer period, snowmelt continues to provide recharge along the basin boundaries and provide the primary source of streamflows entering the basin. Although the trapezoidal channel loses water to the aquifer in this time period, most recharge appears to come from snowmelt along the edges of the basin. The maximum measured leakage rate from the trapezoidal channel into the aquifer was 0.267 cfs for a 1,000 foot length of the trapezoidal channel. This is equivalent to a leakage of 120 gpm. The recharge from ongoing snowmelt and creek leakage props up groundwater elevations to just below the base of Squaw Creek

4.1.3 LATE SUMMER THROUGH FALL CREEK/AQUIFER INTERACTIONS

The late summer through fall time period is characterized by no streamflow in the trapezoidal channel. Snowmelt has ceased and there is no other significant rainfall supplying water to Squaw Creek. Historical photographs show that this period of no streamflow occurred before any significant development of Olympic Valley. Lack of streamflow in western Olympic Valley is therefore not caused by municipal pumping, although its onset may be hastened by pumping. Because there is no flow in the trapezoidal channel, and groundwater levels are below the bottom of Squaw Creek, there is no Creek/Aquifer interaction in western Olympic Valley during this time.

Groundwater is pumped from aquifer storage during this time period. This causes groundwater levels to drop more rapidly than during either of the previous two time periods. Isotope data suggest that water pumped later in this period is older: up to 4 to 6 years old. The pumped groundwater is derived from longer flow paths, and possibly some fracture flow feeding the edges of the basin.

The end of this period is marked by the return of precipitation. Groundwater elevations rebound quickly after the first rainfalls. Groundwater elevations can rebound to near-full basin conditions within days. Runoff from these early rainfall events feeds Squaw Creek. As Squaw Creek begins to flow and groundwater levels rise rapidly, the Creek/aquifer dynamic changes rapidly. Immediately following the first large rainfall, groundwater elevations are still below the Creek bed, and the trapezoidal channel loses water to the shallow aquifer. This dynamic is reversed within a matter of days. Groundwater elevations quickly rise above the level of Squaw Creek, and the creek changes from a losing creek to a gaining creek. Within days after the first major storm, the trapezoidal channel is again draining the shallow aquifer.

Climate change may influence minor aspects of the three time periods, although the three time periods will generally continue to exist as described above. If snowfall is reduced, as is predicted by a number of climate models, the relatively low creek flows of mid-summer and dry creek conditions of late summer may arrive earlier in the year. If the late summer through fall time period is extended because of this timing change, there may not be adequate groundwater storage in Western Olympic Valley to provide for all the municipal needs before the first significant storms of fall. If, however, climate change results in an increase in the number and severity of summer and fall rainstorms, the need for groundwater storage will be lessened. The summer and fall rainstorms will potentially recharge the aquifer in late summer and early fall.

4.2 EAST OLYMPIC VALLEY

East Olympic Valley includes the meadow and golf course areas. Most groundwater pumped from this side of the Valley is for irrigation or private use. Unlike the trapezoidal channel, Squaw Creek meanders through this portion of the valley. The three distinct periods of creek/aquifer interaction observed in West Olympic Valley are not evidenced here.

Squaw Creek generally gains water by draining the shallow aquifer along the entire length of the Creek in East Olympic Valley. The rate of groundwater seepage into Squaw Creek is relatively constant along the length of the creek, with no significant areas of upwelling. Measured groundwater discharge in the meadow constituted about 5% of total stream discharge in early June, 2009 and about 18% of total discharge in early July, 2009. By late July and August, groundwater inflow makes up nearly all of the observed flow in the meadow portion of Squaw Creek. Even in late summer, parts of Squaw Creek in East Olympic Valley continue to be recharged by shallow groundwater. Water in certain pools in late summer show no evidence of evaporation, indicating that the pools are being continually refreshed with new water.

Sediments in the meadow are more clay-rich and silt-rich than sediments in West Olympic Valley, and groundwater moves more slowly through these sediments. Unlike West Olympic Valley, groundwater seeping into Squaw Creek in the meadow is not from the previous year’s snowfall. This groundwater is up to several decades old (Singleton et al., 2008).

SECTION 5
RECOMMENDATIONS

Based on the descriptions of the interactions between Squaw Creek and the shallow aquifers provided above, we propose the following general water management strategies. These are only initial suggestions. The District should develop a formal pumping management strategy. The strategy will incorporate the data and results from the Creek/Aquifer study, and be designed to provide municipal water supplies while minimizing environmental impacts. Many of the ideas strategies presented below will be modified and refined before being incorporated into the strategy document.

1. Move pumping during the year, based on streamflows in the trapezoidal channel. The strategy follows the three distinct time periods of creek/aquifer interaction.
    a. During spring and early summer, wells closest to the trapezoidal channel should be preferentially pumped. Because Squaw Creek flows are many times the total pumping during this period, any direct capture of surface water will have an insignificant impact on total Creek flows. This strategy attempts to store groundwater in the portions of basin distant from Squaw Creek.
    b. During mid-summer, wells farthest away from the trapezoidal channel should be preferentially pumped. This is the time period when pumping has the greatest impact on Squaw Creek flows. These impacts should be minimized by moving pumping away from Squaw Creek. To the degree possible, the groundwater that was stored in spring and early summer in the portions of the basin distant from Squaw Creek should be pumped during this period. One difficulty with this strategy is that the basin may not be large enough to store much water away from the creek. Further analysis during the wellfield optimization and pumping strategy study will estimate the benefit of this strategy
    c. During late summer and fall, operate wells to minimize drawdown. Groundwater pumping in West Olympic Valley has little or no direct impact on Squaw Creek flows during this period, although the pumping may intercept water that would eventually flow to the meadow, and into Squaw Creek. Because there is little or no direct impact on the creek, wells should be operated to minimize impacts to the wells.

While this strategy is conceptually beneficial to creek flows, the benefit to the Squaw Creek will only be known after additional analysis and testing of the strategy. The amount of groundwater that can be stored in Olympic Valley during the first time period may be very limited. However, because the strategy appears to have no significant detriment to Squaw Creek flows; it should be pursued even if the benefit is limited

2. Potentially modify the trapezoidal channel. The trapezoidal channel drains the shallow aquifer in West Olympic Valley. Reducing this drainage would allow more water to be stored in the aquifer for late summer and fall use. An inflatable dam near or beneath Papoose Bridge has been previously discussed as one method of modifying the trapezoidal channel. The shallow lake that would form behind an inflatable dam would reduce the amount of discharge from the aquifer into the trapezoidal channel. Additionally, the water behind the inflatable dam could be released slowly in mid-summer, providing additional flows through the meadow portion of Squaw Creek during this time period.

   Any attempt to modify the trapezoidal channel, however, should acknowledge the flood control benefits of the channel. No modifications should be undertaken that reduce the flood safety benefits of the channel.

3. Reduce pumping in East Olympic Valley. Groundwater discharge into Squaw Creek appears to be an important and significant source of Creek water from mid and late summer through fall. Maintaining relatively high groundwater elevations in the meadow through the fall will result in increased discharges to Squaw Creek during critical times. Because the groundwater seeping into Squaw Creek is all east of Papoose Bridge during late summer and fall, pumping in East Olympic Valley will have bigger impacts on summer creek flows than pumping in West Olympic Valley. Pumping in East Olympic Valley should be moved as far west as possible. Moving pumping out of East Olympic Valley will have the added benefit of reducing impacts on wetlands in the Valley

4. Map and protect recharge areas along edge of Valley floor to retain infiltration and avoid contamination. Although mapping recharge areas is an inexact procedure, it is a recent requirement of Groundwater Management Plans. The study results can guide our recharge area mapping by showing that most groundwater pumped by municipal wells comes from infiltration along the sides of the basin at an average elevation of approximately 6350 feet. This area should be maintained as protected, and potentially enhanced, recharge areas. These areas should be protected from contamination. The rapid movement of groundwater through sediments in West Olympic Valley will make it difficult to contain and remediate any contamination before it reaches a municipal well.

Because of the high susceptibility of municipal wells to any groundwater contamination in the recharge areas, a secondary source of supply should be investigated to provide reliability and redundancy.

5. Any expansion in the existing wellfield should focus on the west side of the Valley, and should be designed to allow flexibility in pumping location. Wellfield expansion should acknowledge the pumping strategies outlined above.

SECTION 6
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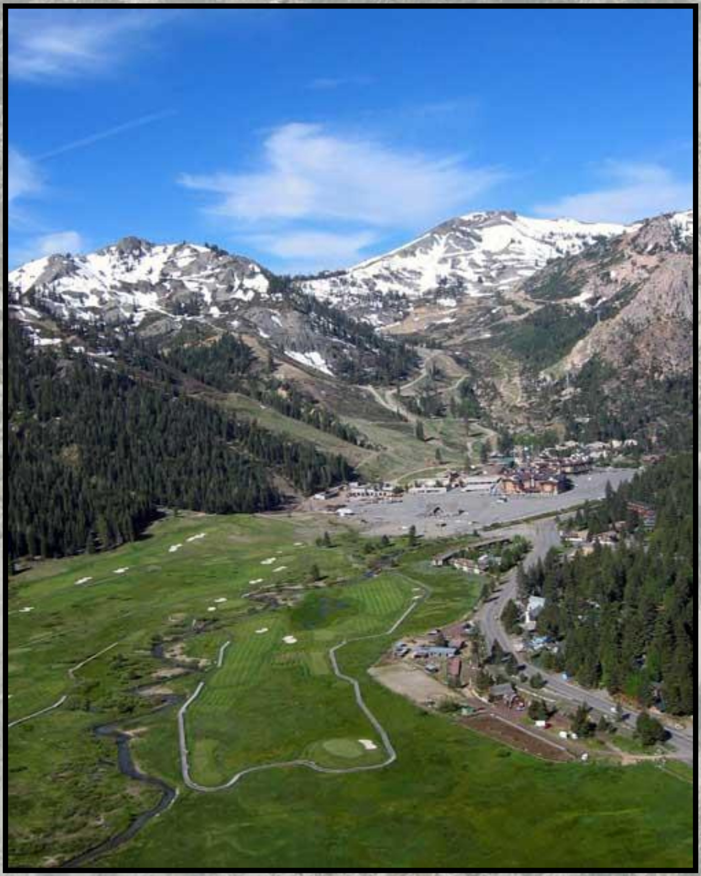
Squaw Valley Creek/Aquifer Interaction Study Final Report

Grant Agreement 4600008205

Prepared for:
Squaw Valley Public
Service District



Prepared by: HydroMetrics WRI

March 2011

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ABBREVIATIONS

bgs	Below ground surface
cfs	cubic feet per second
cm	centimeter
GWMP	Groundwater Management Plan
NAD83	North American Datum, 1983
NGVD	National Geodetic Vertical Datum
PSP	Project Solicitation Package
SVMWC	Squaw Valley Mutual Water Company
SVPSD	Squaw Valley Public Service District

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EXECUTIVE SUMMARY

This final report details the activities undertaken by the Squaw Valley Public Service District (SVPSD) for Phase I of the Squaw Valley Creek/Aquifer Interaction Study. This Phase of the study was funded by the State of California under the Local Groundwater Assistance Grant program, agreement number 4600008205.

The goals of the study, as identified in the Project Solicitation Package (PSP) included:

1. Initiate Element 2, item 2 of the Olympic Valley Groundwater Management Plan (GWMP), which calls for supporting a creek/aquifer interaction study.

2. Identify the impacts of well pumping on shallow groundwater adjacent to Squaw Creek.

3. Develop data that can be used to manage groundwater pumping such that it minimizes impacts on Squaw Creek.

All three goals were fully realized.

The project comprised five tasks:

Task 1: Pre–Construction Activities.
Task 2: Drilling, Well Construction, and Development.
Task 3: Equipping Monitoring Wells.
Task 4: Aquifer Testing.
Task 5: Reporting.

Unusually early winter weather, permitting difficulties, and recent technological advances in estimating stream/aquifer interactions led to a few scope modifications during the course of the project. All modifications were pre-approved and documented in quarterly reports. All tasks have been completed in accordance with the revised project scope.

TASK 1: PRE-CONSTRUCTION ACTIVITIES

This task included developing drilling specifications, securing a drilling contractor, and completing the permitting process. Well permits for the four new monitoring wells were obtained from Placer County Department of Environmental Health Services.

Well specifications were developed for all four monitoring wells. Three monitoring wells were installed using sonic drilling techniques. The deep PlumpJack Squaw Valley Inn was installed using air-rotary drilling techniques.

TASK 2: DRILLING, WELL CONSTRUCTION, AND WELL DEVELOPMENT

This task included installing four new monitoring wells adjacent to Squaw Creek; installing six temporary temperature probes in the base of the trapezoidal channel section of Squaw Creek; installing four temporary piezometers in the base of the trapezoidal channel section of Squaw Creek, and installing two stilling wells in the trapezoidal channel section of Squaw Creek.

The four new monitoring wells were installed between December 10, 2008 and June 3, 2010. Drilling was delayed twice due to weather problems, resulting in the extended drilling schedule. Drilling techniques were used that do not produce drilling mud in order to prevent accidental releases into the adjacent Squaw Creek.

The two Poulsen property monitoring wells and the shallow PlumpJack Squaw Valley Inn well were installed by Water Development Corporation in December, 2008, using an air-rotary drill rig. The deep PlumpJack Squaw Valley Inn well was installed between June 1 and June 3, 2010. The well was drilled using a sonic drill rig by Boart Longyear Inc, which produced a continuous core during drilling. Well depth and well completion information are summarized on Table ES- 1.

Table ES- 1: Monitoring Well Details

	Poulsen Shallow	Poulsen Deep	PlumpJack Shallow	PlumpJack Deep
Method	Air-rotary	Air-rotary	Air-rotary	Sonic
Hole Depth	31 feet	135 feet	39 feet	133 feet
Completed Depth	29 feet bgs	105 feet bgs	34 feet bgs	132 feet
Elevation	6192.31	6191.77	6210.73 feet	6209.60 feet
Borehole Diameter	6 inches	6 inches	6 inches	6 inches
Casing Diameter	2 inches	2 inches	2 inches	2 inches
Casing Material	Schedule 40 PVC	Schedule 40 PVC	Schedule 40 PVC	Schedule 40 PVC
Screened Interval	9 – 29 feet bgs	85 – 105 feet bgs	14 – 34 feet bgs	102 – 132 feet bgs

All wells were installed in accordance with relevant local and state regulations. A County inspector was on site to observe the placement of the annular seal in all four monitoring wells.

Six temperature probes were installed in the trapezoidal channel portion of Squaw Creek on May 27, 2009. Three temperature probes were installed in the creek near well SVPSD #4R and three probes were installed in the creek near wells SVPSD MW-5S and SVPSD MW-5D. Each temperature probe was outfitted with three data loggers; each data logger located at a different depth below the creek bed elevation. Data from the temperature probes facilitate estimating flow of groundwater into and out of Squaw Creek.

Three temporary piezometers were installed in the base of Squaw Creek, and one temporary piezometer was installed on the bank of Squaw Creek on June 3, 2009. The piezometers were located adjacent to the temperature probes to promote coordinated analyses of temperature and water level data. Each piezometer was outfitted with a Micro-Diver transducer with built-in data logger. Two stilling wells were installed at the piezometer sites to record water levels in Squaw Creek. Each stilling well was outfitted with a Micro-Diver transducer.

All reference points for the newly installed monitoring wells, as well as the temporary piezometers and stilling wells were surveyed by Andregg Geomatics on October 1, 2010. The surveying was performed per GeoTracker guidelines and specifications.

TASK 3: EQUIPPING MONITORING WELLS

New pressure transducers with built-in data loggers were installed in 14 wells on June 3, 2009 and August 27, 2010. The following 14 wells were equipped with new data loggers.

- Poulsen Shallow
- Poulsen Deep
- PlumpJack Shallow
- PlumpJack Deep
- SVPSD MW-5S
- SVPSD MW-5D
- SVPSD #4R
- RSC-312
- RSC-318
- RSC-328
- RSC-324
- RSC-311
- RSC-317
- RSC-327

The transducers are currently recording hourly groundwater elevations.

TASK 4: AQUIFER TESTING

Two constant rate aquifer tests were conducted on well SVPSD #2. Groundwater elevation data were collected during both aquifer tests from eight monitoring and production wells. Groundwater elevation data were additionally collected during both tests from the four temporary piezometers and two stilling wells. Groundwater temperature data were collected from the six temporary temperature probes during each test.

The first aquifer test was conducted on well SVPSD #2 between June 23 and June 25, 2009. Squaw Creek was flowing during the test. The test was run for 52 hours. During the test, well SVPSD #2 was pumped at an average rate of 319 gallons per minute.

The second aquifer test was conducted between September 8 and September 10, 2010. Squaw Creek was dry during the test. The second aquifer test was run for 51 hours. During the test, well SVPSD#2 was pumped at an average rate of 303 gallons per minute.

TASK 5: REPORTING

Reporting consisted of submitting quarterly reports and drafting this final report. Every quarterly report was prepared and submitted on time. This report is the final submittal under Task 5.

COST AND SCHEDULE

The Squaw Valley Creek/Aquifer Interaction Study has been completed within the original budget. Although the total costs remain within the original project budget, some positive and negative cost variances occurred on individual tasks. To keep individual task costs in line with the task budgets, modifications to the individual task budgets were requested by SVPSD in October 2010. No change to the total grant amount was requested. Staff of DWR granted SVPSD's budget modification request.

The schedule was updated every quarter based on progress made, weather delays, and scope changes. A revised schedule was included in every quarterly report.

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SECTION 1
INTRODUCTION AND BACKGROUND

This final report details the activities undertaken by the Squaw Valley Public Service District (SVPSD) for Phase I of the Squaw Valley Creek/Aquifer Interaction Study. This Phase of the study was funded by the State of California under the Local Groundwater Assistance Grant program, agreement number 4600008205.

1.1 SETTING AND BACKGROUND

Squaw Valley is a glacially carved valley in the Sierra Nevada of California. The Valley is situated west of Lake Tahoe, at an elevation of approximately 6,200 feet (Figure 1). Squaw Valley measures approximately 2.5 miles long by 0.4 miles wide, covering an area of approximately 600 acres. Steep mountains bound the Valley on the North, West, and South. A terminal moraine on the Valley's eastern side separates the Valley from the Truckee River. The Valley is drained by Squaw Creek. The north and south forks of Squaw Creek enter along the Valley's western side. Squaw Creek exits the Valley through the terminal moraine on the Valley's eastern side.

All water used in Squaw Valley is derived from groundwater pumping. Water for municipal and commercial uses is served by two water companies. The SVPSD is a County Water District formed under Division 12 of the California Water Code; the Squaw Valley Mutual Water Company (SVMWC) is a non-profit, member owned corporation. In addition to the two water companies, groundwater is pumped for domestic and irrigation uses by the Resort at Squaw Creek, the PlumpJack Squaw Valley Inn, and the Squaw Valley Ski Corporation.

Squaw Creek and its tributaries are the only significant surface water bodies in Squaw Valley. Two forks of Squaw Creek, the South Fork and Shirley Canyon, enter Squaw Valley along the western margin (Figure 2). Shirley Canyon is the larger of the two forks of Squaw Creek, with flows of up to 138 cubic feet per second (cfs) recorded during Water Years 2003 and 2004. Over the same time period, the highest flow recorded in the South Fork was 103 cfs.

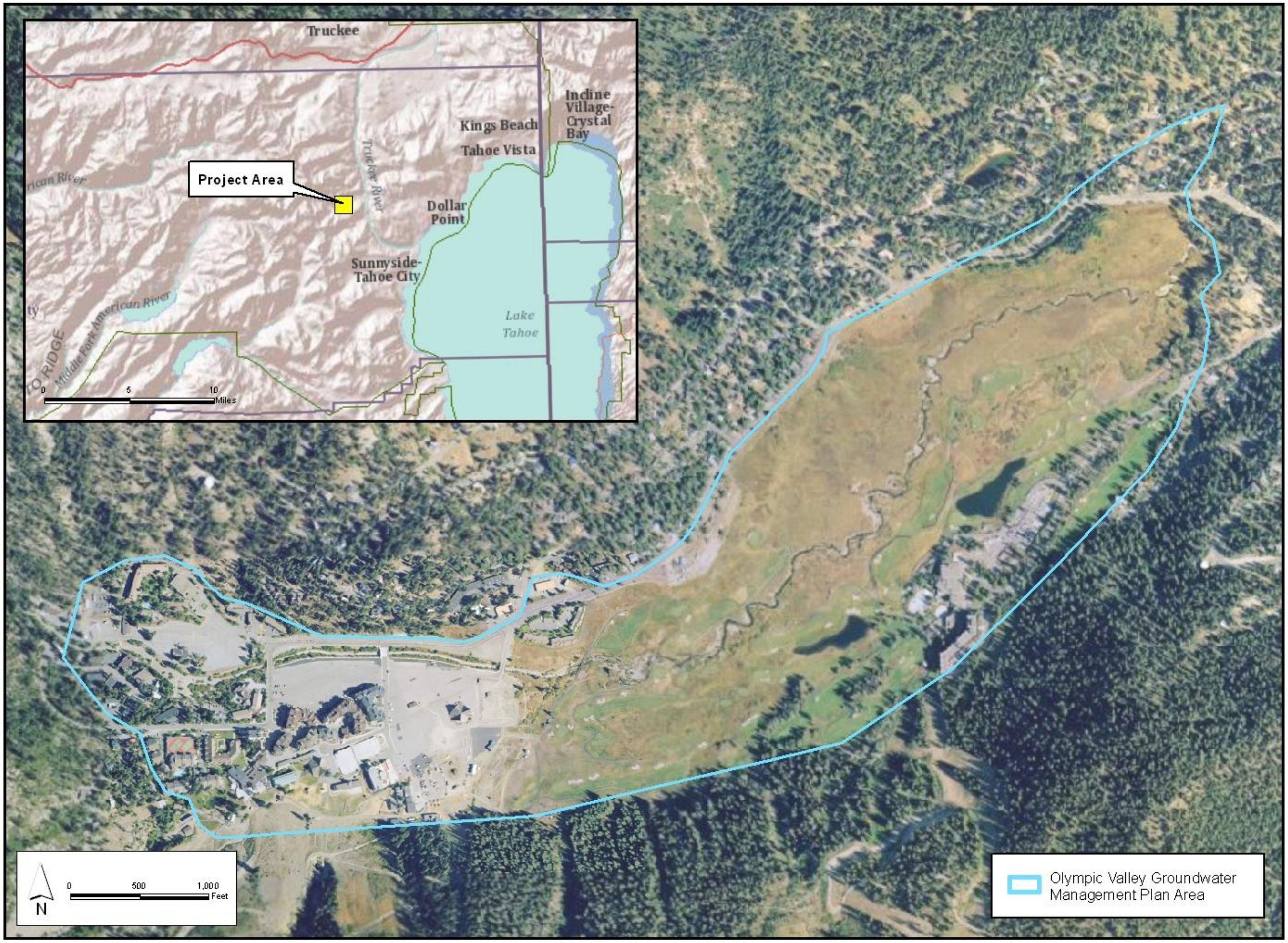

Figure 1: Squaw Valley Location and Management Area Boundary

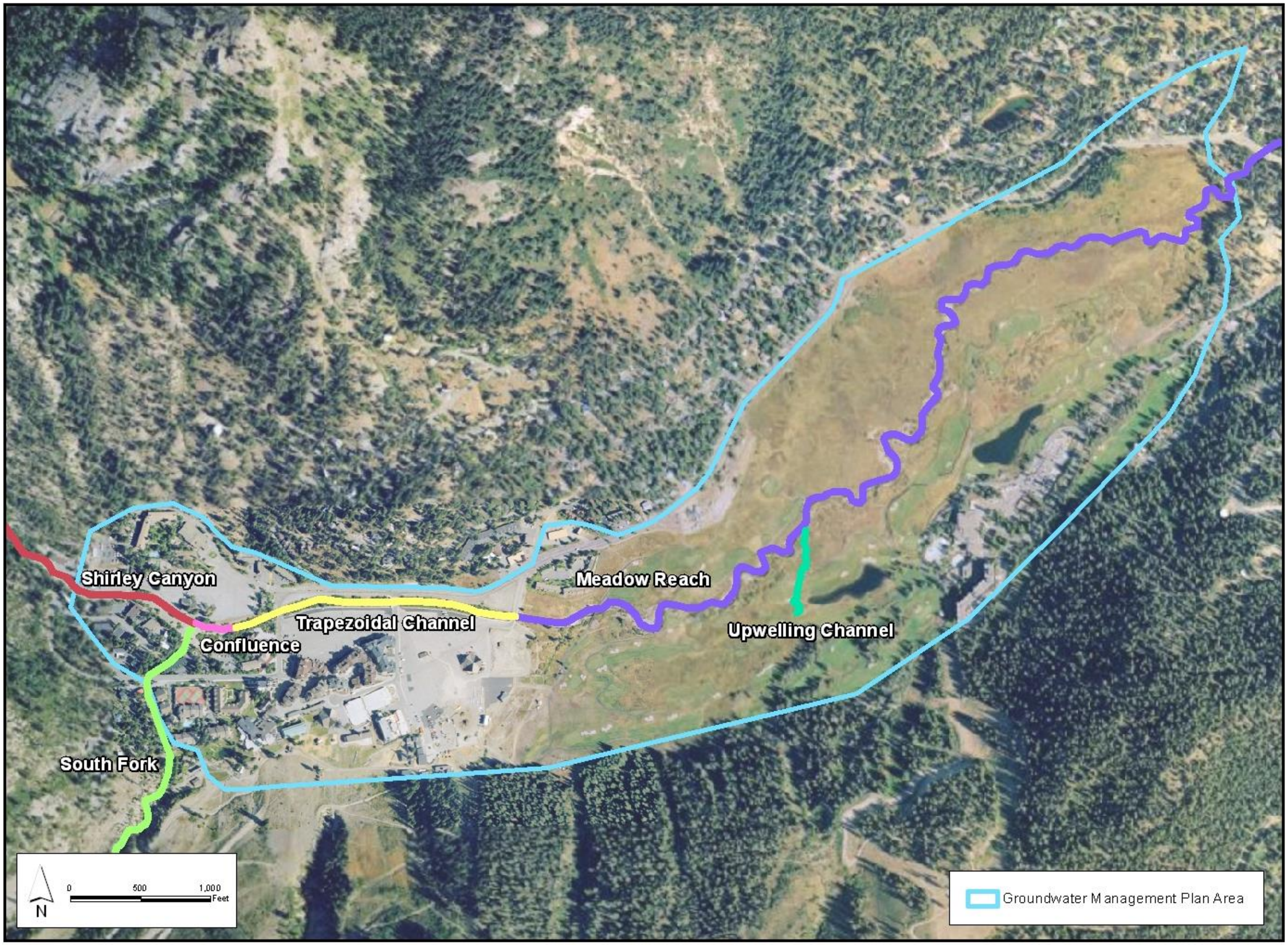

Figure 2: Squaw Creek Location and Reaches

The two main forks converge in an area locally known as the confluence. The confluence is a wide gravel filled portion of Squaw Creek that has generally maintained its natural configuration. Water flows from the confluence into a manmade trapezoidal channel. This channel is not lined, and runs generally parallel to Squaw Valley Road to the bridge on the eastern end of the Squaw Valley parking lot.

Below the bridge on the eastern end of the Squaw Valley ski resort parking lot, Squaw Creek meanders through a meadow in a relatively natural channel. Squaw Creek exits the Valley beneath Squaw Valley Road Bridge on the eastern end of the meadow, and flows through an incised channel cut into the terminal moraine to the Truckee River.

1.2 PROJECT GOALS AND OUTCOMES

The Project Solicitation Package (PSP) identified three goals. Each goal and the associated outcomes are listed below.

1. Initiate Element 2, item 2 of the Olympic Valley GWMP, which calls for supporting a creek/aquifer interaction study.

   This goal was fully realized. Supporting a creek/aquifer interaction study was an important element of the Olympic Valley GWMP, assuring that the plan is collaborative and addresses all stakeholder concerns. The creek/aquifer interaction study was not only supported, it was designed and initiated under this agreement.

2. Identify the impacts of well pumping on shallow groundwater adjacent to Squaw Creek.

   All data necessary to support this goal have been collected. The data will be analyzed, and the pumping impacts identified, under Phase II of this study.

3. Develop data that can be used to manage groundwater pumping such that it minimizes impacts on Squaw Creek.

   This goal was fully realized. All data necessary to mange groundwater pumping such that it minimizes impacts on Squaw Creek have been collected. The Actions *needed to minimize the pumping impacts will be developed in Phase II of this study.*

1.3 SUMMARY OF COMPLETED WORK

1.3.1 PROJECT SOLICITATION PACKAGE SCOPE

The original scope of work proposed in the PSP consisted of five tasks. Each of the original tasks is described briefly below:

Task 1: Pre–Construction Activities. This task included developing drilling specifications, securing a drilling contractor, and completing the permitting process.

Task 2: Drilling, Well Construction, and Development. This task included installing six new monitoring wells adjacent to Squaw Creek: three shallow wells and three deep wells. The monitoring wells will provide groundwater level data from the aquifer tests as well as long-term monitoring data.

Task 3: Equipping Monitoring Wells. This task consisted of installing permanent pressure transducers in each of the six new monitoring wells, along with eight existing monitoring wells adjacent to Squaw Creek. The data loggers provide groundwater level data during the aquifer tests, as well as long-term groundwater level data that show both daily and seasonal fluctuations.

Task 4: Aquifer Testing. Three 24-hour aquifer tests were proposed at three different wells. These were intended to estimate the impact of pumping on streamflows from three different locations within the Valley.

Task 5: Reporting. This task covered quarterly reporting, meetings, and final reporting.

1.3.2 SCOPE MODIFICATIONS

Unusually early winter weather, permitting difficulties, and recent advances in technologies for estimating stream/aquifer interactions led to a few scope modifications during the course of the project. All modifications were pre-approved and documented in quarterly reports. These scope modifications are detailed below.

Task 1: Pre–Construction Activities. No scope modifications were necessary, however this task proved more difficult than anticipated due to scope modifications in Task 2. Difficulties included additional site access requirements for the added temporary piezometers and temperature probes; and unanticipated extended permitting issues resulting from weather-caused delays. All of these difficulties were successfully addressed during the project. The added time and expense needed to negotiate access agreements for the temporary piezometers and temperature probes was offset by the cost savings of replacing two monitoring wells with the temporary piezometers and temperature probes. The added time and expense needed to address the extended permitting issues was absorbed by the project sponsor.

Task 2: Drilling, Well Construction, and Development. Permitting difficulties along with recent technological advances in estimating stream/aquifer interactions led to scope modifications in Task 2. These included:

- Installing four temporary piezometers in the trapezoidal channel section of Squaw Creek. These temporary piezometers measure groundwater elevations directly beneath Squaw Creek, allowing calculation of shallow vertical gradients that drive groundwater into and out of Squaw Creek.
- Installing six temporary temperature probes in the trapezoidal channel section of Squaw Creek. Temperature has become the tracer of choice by the U.S. Geological Survey and others for measuring stream/aquifer interactions.
- Removing two of the planned monitoring wells from the drilling plan.

Task 3: Equipping Monitoring Wells. The four new temporary piezometers and six new temporary temperature probes installed in trapezoidal channel in Task 2 required additional monitoring well equipment. The additional equipment and effort included:

- Equipping each of the four temporary piezometers with transducers that collect shallow groundwater elevations every 15 minutes.
- Equipping each of the six temporary temperature probes with three temperature data loggers; for a total of 18 temperature data loggers.

The temperature data loggers are installed at various depths to identify vertical temperature gradients.

- Removing the temporary equipment during the winter to avoid losing the equipment in floods, and re-installing the equipment after the threat of floods has passed.

The added time and expense needed to equip the temporary piezometers and temporary temperature probes with data loggers was offset by the cost savings realized from deleting two of the monitoring wells

Task 4: Aquifer Testing. The aquifer testing program was modified to take advantage of the temporary monitoring equipment installed in Task 2. The three 24-hour tests were replaced with two 50-hour tests at the same well. Extra pumping time was added to each test to ensure that the cone of depression was observable in the temporary piezometers beneath Squaw Creek.

Task 5: Reporting. No scope modifications were necessary; however the weather delays resulted in considerably more quarterly reports than originally scoped.

1.3.3 WORK COMPLETED

All work described under the modified scope is complete. This report is the final submittal for this project. All data have been collected as planned. The extent of data collected are expanded on in Section 2.

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SECTION 2
DESCRIPTION OF WORK PERFORMED

This section provides detailed descriptions of the work performed. Supporting information, including raw data and photographs, are provided in Appendices A through G as well as the enclosed CD.

2.1 TASK 1: PRE–CONSTRUCTION ACTIVITIES

Pre-construction activities included obtaining access to drilling sites, obtaining required well permits, developing well specifications, and contracting drillers. As discussed in Section 1.3.2, three locations required access: the PlumpJack Squaw Valley Inn; the Poulsen property at the west end of the meadow; and the trapezoidal channel.

Well permits for the four permanent wells were obtained from the Placer County Department of Environmental Health Services. Unusually early snowfall in 2008 prevented all four wells from being installed at the same time. The fourth well, which was the deep PlumpJack Squaw Valley Inn well, had to be installed at a later date. It therefore required a separate well permit. Both the original well permit for all four monitoring wells and the supplemental well permit for installing the deep PlumpJack Squaw Valley Inn well are included in Appendix A.

Well specifications were developed for all four monitoring wells. Three monitoring wells were installed using sonic drilling techniques. The deep PlumpJack Squaw Valley Inn was installed using air-rotary drilling techniques. The specifications for the well installations are included in Appendix B.

Two separate drillers were contracted for the two well installation events. The two wells on the Poulsen property and the shallow well at the PlumpJack Squaw Valley Inn were installed by Water Development Corporation, using air-rotary drilling techniques. The deep well at the PlumpJack Squaw Valley Inn was installed by Boart Longyear using a sonic drilling technique.

2.2 TASK 2: DRILLING, WELL CONSTRUCTION, AND DEVELOPMENT

2.2.1 MONITORING WELLS

Four new monitoring wells were installed between December 10, 2008 and June 3, 2010. Drilling was delayed twice due to weather problems, resulting in the extended drilling schedule. Details of the four monitoring wells are summarized in Table 1. Locations of the four monitoring wells are shown on Figure 3.

The monitoring wells are located in areas that are covered with snow in the winter, and used for recreation in the summer. To accommodate these factors, the window for drilling and installing the wells was limited to a couple weeks every year in the spring and fall. Drill rig availability therefore became an important factor in selecting a drilling technique. In addition to drill rig availability, mudless drilling techniques were used in order to prevent accidental releases into the adjacent Squaw Creek.

The two Poulsen property monitoring wells and the shallow PlumpJack Squaw Valley Inn well were installed by Water Development Corporation in December, 2008, using an air-rotary drill rig. Drill cuttings were obtained at every five foot interval. A State of California professional geologist from HydroMetrics WRI was onsite throughout the well drilling, installation, and development. Snow storms prevented Water Development Corporation from installing the deep PlumpJack monitoring well.

The deep PlumpJack Squaw Valley Inn well was installed between June 1 and June 3, 2010. The well was drilled using a sonic drill rig by Boart Longyear Inc. Continuous cores were obtained during the drilling. A State of California professional geologist from HydroMetrics WRI was onsite throughout the well drilling, installation, and development. Additional details on the well installations at each site are included below.

Figure 3: Location of New Monitoring Wells

Table 1: Summary of Monitoring Well Details

	Poulsen Shallow	Poulsen Deep	PlumpJack Shallow	PlumpJack Deep
Dates installed	12/10/08 – 12/12/08	12/10/08 – 12/12/08	12/17/08 – 12/19/08	6/01/10 – 6/03/10
Driller	Water Development Corp.	Water Development Corp.	Water Development Corp.	Boart Longyear
Method	Air-rotary	Air-rotary	Air-rotary	Sonic
Hole Depth	31 feet	135 feet	39 feet	133 feet
Completed Depth	29 feet bgs	105 feet bgs	34 feet bgs	132 feet
Top of Casing Elevation	6192.31	6191.77	6210.73 feet	6209.60 feet
Borehole Diameter	6 inches	6 inches	6 inches	6 inches
Casing Diameter	2 inches	2 inches	2 inches	2 inches
Casing Material	Schedule 40 PVC	Schedule 40 PVC	Schedule 40 PVC	Schedule 40 PVC
Screened Interval	9 – 29 feet bgs	85 – 105 feet bgs	14 – 34 feet	102 – 132 feet bgs

POULSEN PROPERTY WELLS

The two Poulsen property wells were installed between December 10 and December 12, 2008. The borehole for the deep Poulsen property well was drilled to 135 feet below ground surface. Gray silt was encountered between 105 and 135 feet below ground surface. The deep well was screened above the silt, from 85 to 105 feet below ground surface. The well screen consisted of 2-inch schedule 40 PVC with 0.02-inch factory cut slots.

The borehole for the shallow Poulsen property well was drilled to 31 feet below ground surface. The shallow well was screened between 9 and 29 feet below ground surface. This well screen was placed high in the borehole so that it would cross the shallow water table that is connected to nearby Squaw Creek. The well screen consisted of 2-inch schedule 40 PVC with 0.02-inch factory cut slots.

The gravel pack for both Poulsen property wells consisted of Cemex #3 sand. Gravel pack in the deep well was placed from the bottom of the borehole to 79 feet below ground surface: six feet above the top of the screen. Gravel pack in the shallow well was placed from the bottom of the borehole to 6.7 feet below ground surface: 2.3 feet above the top of the screen. The gravel packing was monitored and documented, and the final depth to the top of the gravel pack was measured and recorded by the on-site geologist.

Bentonite chip transition seals were placed in the annulus on top of the gravel pack. Approximately 5 feet of bentonite chips were placed in each of the well's annuluses. The placement of the bentonite chips was monitored and documented; and the final depth to the top of the bentonite chips was measured and recorded by the on-site geologist.

Neat cement annular seals were placed in the well annuluses through tremmie pipes. The cement for the deep well included 5% bentonite to slow the curing process and protect the integrity of the well casing. The cement for the shallow well contained no bentonite. A County inspector was on site to observe the sealing of both wells. Both wells were completed with steel pipes that stick up approximately 4 feet above ground surface. The steel pipes were outfitted with locking covers.

Well logs for the Poulsen property wells are all included in Appendix C. Photos of the drilling operation are included in Appendix D.

PLUMPJACK SQUAW VALLEY INN WELLS

The shallow PlumpJack Squaw Valley Inn well was installed between December 17 and December 19, 2008. The borehole for the shallow PlumpJack Squaw Valley Inn well was drilled to 39 feet below ground surface. Heaving sand prevented the well from being completed to 39 feet bgs. The well was screened between 14 and 34 feet below ground surface. The well screen consisted of 2-inch schedule 40 PVC with 0.02-inch factory cut slots.

The gravel pack for the shallow PlumpJack Squaw Valley Inn well consisted of Cemex #3 sand. Gravel pack was placed from the bottom of the borehole to 11 feet below ground surface: three feet above the top of the screen. The gravel packing was monitored and documented; and the final depth to the top of the gravel pack was measured and recorded by the on-site geologist.

A two foot bentonite chip transition seal was placed in the well annulus above the gravel pack. The placement of the bentonite chips was monitored and documented; and the final depth to the top of the bentonite chips was measured and recorded by the on-site geologist.

A neat cement annular seal was placed in the well annulus through a tremmie pipe. The cement contained no bentonite. A county inspector was on site to observe the sealing of the shallow well. The well was completed with a traffic-bearing at-grade completion.

The deep PlumpJack Squaw Valley Inn well was installed between June 1 and June 3, 2010. The borehole for the deep PlumpJack Squaw Valley Inn well was drilled to 133.5 feet below ground surface. The bottom of the borehole encountered granitic bedrock. The well was screened between 102 and 132 feet below ground surface. The well screen consisted of 2-inch schedule 40 PVC with 0.02-inch factory cut slots.

The gravel pack for the deep PlumpJack Squaw Valley Inn well consisted of Lonestar #3 sand. Gravel pack was placed from the bottom of the borehole to 97 feet below ground surface: five feet above the top of the screen. The gravel packing was monitored and documented; and the final depth to the top of the gravel pack was measured and recorded by the on-site geologist.

A five foot bentonite chip transition seal was placed in the well annulus above the gravel pack. The placement of the bentonite chips was monitored and documented; and the final depth to the top of the bentonite chips was measured and recorded by the on-site geologist.

A neat cement annular seal was placed in the well annulus through a tremmie pipe. The cement contained 5% bentonite to slow the curing process and protect the integrity of the well casing. A county inspector was on site to observe the sealing of the deep well. The well was completed with a traffic-bearing at-grade completion.

Well logs for the PlumpJack Squaw Valley Inn wells are included in Appendix C. Photos of the drilling operation are included in Appendix D.

2.2.2 TEMPERATURE PROBES

Six temperature probes were installed in the trapezoidal channel portion of Squaw Creek on May 27, 2009. Three temperature probes were installed in the creek near well SVPSD #4R and three probes were installed in the creek near wells SVPSD MW-5S and SVPSD MW-5D. The locations of the six temperature probes are shown in Figure 4. Data from the temperature probes help estimate the flow of groundwater into and out of Squaw Creek.

The temperature probes were based on a design provided by Dr. Andrew Fisher from the University of California, Santa Cruz (personal communication). The probes are designed to measure ambient groundwater temperature at three depths below the streambed. This design has been developed to gather data that can be analyzed using the techniques outlined in Hatch et al. (2006). Details on the depth of the data loggers in each temperature probe are shown on Table 2. The temperature data loggers were set to record temperature every 15 minutes. A schematic showing the probe design is shown in Figure 5.

The data loggers were removed from the probes on November 4, 2009 to prevent them from being lost in winter floods. The data loggers were re-installed in the probes on August 27, 2010, prior to the second aquifer test. The data loggers and probes were completely removed from the trapezoidal channel on October 18, 2010. Photos of the probes, probe installation, and probe removal are included in Appendix E.

Figure 4: Temperature Probe and Stream Piezometer Locations

Table 2: Temperature Probe Construction Details

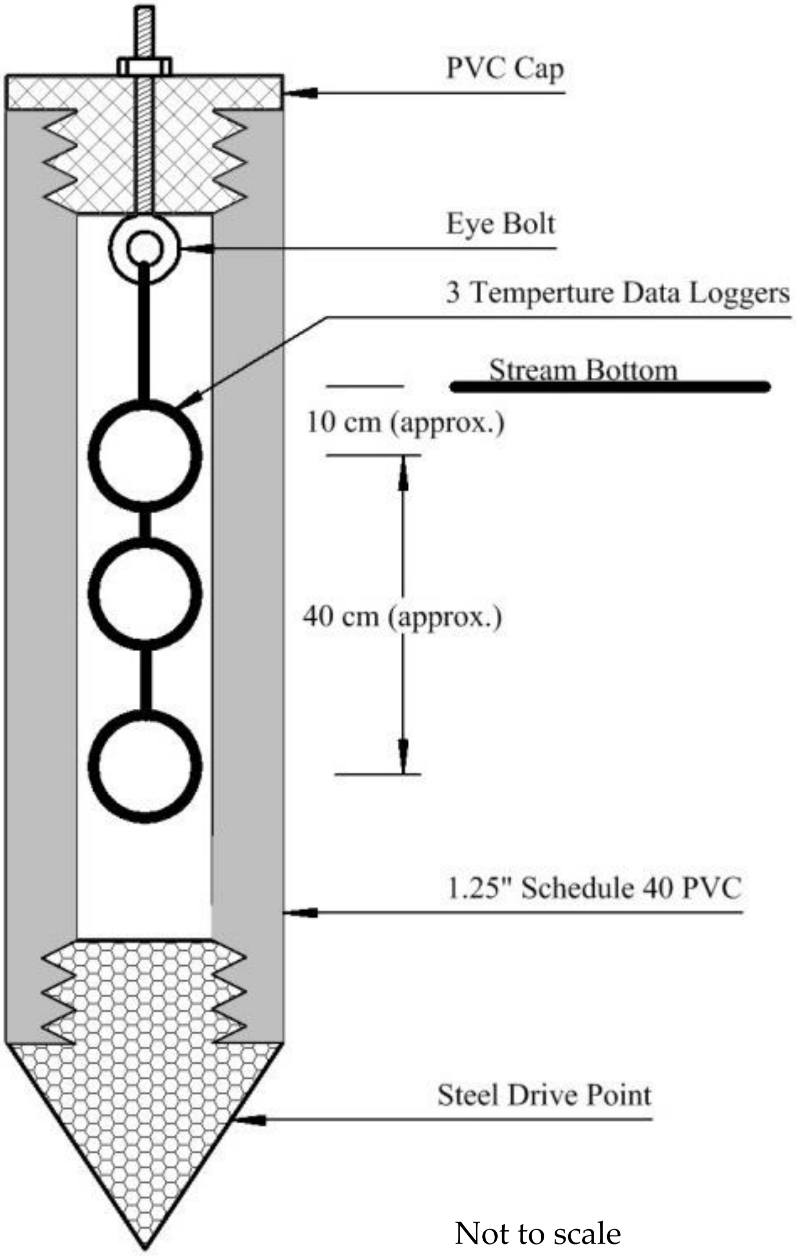
Temperature Probe	Depth to First Data Logger (cm bgs)	Depth to Second Data Logger (cm bgs)	Depth to Third Data Logger (cm bgs)
Near SVPSD #4R - South	9.8	24.8	46.9
Near SVPSD #4R – Mid	9.3	24.3	46.5
Near SVPSD #4R – North	9.0	24.8	48.5
Near SVPSD 5S/5D – South	10.0	25.4	47.1
Near SVPSD 5S/5D – Mid	10.2	25.9	46.8
Near SVPSD 5S/5D – North	11.0	25.8	47.3

2.2.3 IN-STREAM PIEZOMETERS

Three temporary piezometers were installed in the base of Squaw Creek, and one temporary piezometer was installed on the bank of Squaw Creek on June 3, 2009. The piezometers were located adjacent to the temperature probes to promote coordinated analyses of temperature and water level data. Groundwater level data from the temporary piezometers assist with estimating the creek/aquifer interactions.

The piezometers were constructed of ¾-inch threaded steel tubes. A screened drive point was threaded onto the end of each tube, and the piezometers were driven into the stream bottom with a slide hammer. Each piezometer was outfitted with a Micro-Diver transducer with built-in data logger. The transducers had 10 meter ranges and 0.2 centimeter (cm) resolutions. A photo of the transducers is included in Appendix E.

Two stilling wells were installed at the piezometer sites to record water levels in Squaw Creek. Each stilling well was outfitted with a Micro-Diver transducer with built-in data logger. The combination of water levels in the piezometers and water levels measured in the stilling wells allows us to calculate vertical groundwater gradients in the shallow sediments directly beneath Squaw Creek.



Not to scale

Figure 5: Temperature Probe Schematic

The Micro-Diver transducers were removed from the piezometers and stilling wells on November 4, 2009 to prevent them from being lost in winter floods. The transducers were re-installed in the piezometers on August 27, 2010, prior to the second aquifer test. The transducers and piezometers were completely removed from the trapezoidal channel on October 18, 2010. Piezometer locations are shown in Figure 4.

2.2.4 SURVEYING

All reference points for the newly installed monitoring wells, as well as the temporary piezometers and stilling wells were surveyed by Andregg Geomatics on October 1, 2010. The surveying was performed per GeoTracker guidelines and specifications. The horizontal location of the reference points were surveyed to the North American Datum of 1983, California State Plane Coordinate System, Zone 2. The vertical elevation of the reference points were surveyed to within 0.01 foot precision, referenced to NGVD29.

The temperature probes were not surveyed, because all data analyses are referenced to distance below ground surface. The distance below ground surface of each temperature data logger is shown in Table 2.

Survey data are summarized in Table 3. Complete survey data are included in Appendix F.

Table 3: Summary of Survey Data

NAD83 - California State Plane Coordinates Zone 2 - US Survey Feet
NGVD29 - Based on BM H-172 (PID KS0274) EL: 6177.99

FIELD_PT_NAME	XY_SURVEY_DATE	LATITUDE	LONGTITUDE	NORTHING	EASTING	ELEVATION
MW 5 Deep; PVC Pipe	10/1/2010	39.1979586	-120.2300327	2202983.734	7063225.154	6197.74
MW 5 Shallow; PVC Pipe	10/1/2010	39.1979623	-120.2300576	2202985.038	7063218.054	6197.63
Stilling Well near 5D/5S; PVC Pipe	10/1/2010	39.1980844	-120.2300289	2203029.557	7063225.318	6187.75
Deep Piezometer near 5D/5S; Steel Pipe	10/1/2010	39.1980844	-120.2300294	2203029.545	7063225.202	6187.72
Poulsen Deep; PVC Pipe	10/1/2010	39.1977463	-120.2286313	2202914.142	7063623.726	6191.77
Poulsen Deep; Steel Casing	10/1/2010	39.1977468	-120.2286313	2202914.327	7063623.730	6192.04
Poulsen Shallow; PVC Pipe	10/1/2010	39.1977616	-120.2286477	2202919.646	7063618.962	6192.31
Poulsen Shallow; Steel Casing	10/1/2010	39.1977622	-120.2286476	2202919.834	7063618.986	6192.50
SCPSD Well 4R; Sounding Tube	10/1/2010	39.1978166	-120.2319902	2202921.204	7062671.521	6204.90
Stilling Well near 4R; PVC Pipe	10/1/2010	39.1984107	-120.2320092	2203137.427	7062661.918	6188.46
Shallow Piezometer near 4R; Steel Pipe	10/1/2010	39.1984107	-120.2320095	2203137.436	7062661.833	6188.53
Deep Piezometer near 4R; Steel Pipe	10/1/2010	39.1984103	-120.2319939	2203137.364	7062666.277	6188.59
Bank Piezometer near 4R; Steel Pipe	10/1/2010	39.1983864	-120.2320039	2203128.635	7062663.611	6188.55
PlumpJack Shallow; PVC Pipe	10/1/2010	39.1974515	-120.2374377	2202758.283	7061130.612	6210.73
PlumpJack Shallow; Steel Grate	10/1/2010	39.1974519	-120.2374382	2202758.431	7061130.471	6211.05
PlumpJack Deep; Steel Grate	10/1/2010	39.1974262	-120.2372503	2202750.109	7061183.898	6209.60
PlumpJack Deep; PVC Pipe	10/1/2010	39.1974255	-120.2372507	2202749.821	7061183.780	6209.36
MW 5 Deep; Steel Grate	10/1/2010	39.1979593	-120.2300325	2202983.987	7063225.197	6198.25
MW 5 Shallow; Steel Grate	10/1/2010	39.1979633	-120.2300574	2202985.296	7063218.128	6198.30

2.3 TASK 3: EQUIPPING MONITORING WELLS

In accordance with the modified scope of work, new pressure transducers were installed in 14 wells. Competitive bids for the transducers were received from three companies:

Quotes were obtained by SVPSD from the following vendors:

Rockware
2221 East Street, Suite 101
Golden, CO. 80401
Tel: (303) 278-3534

Pine Environmental Services, Inc.
92 North Main Street, Building 20
Windsor, NJ 08561
Tel: (800) 3019663

Schlumberger Water Services
6590 South McCarran Boulevard
Suite A, Reno, Nevada 89509
Tel: (519) 746-1798

The monitoring equipment was installed in monitoring wells on June 3, 2009 and August 27, 2010. Figure 6 shows the locations of all 14 data loggers installed as part of this project.

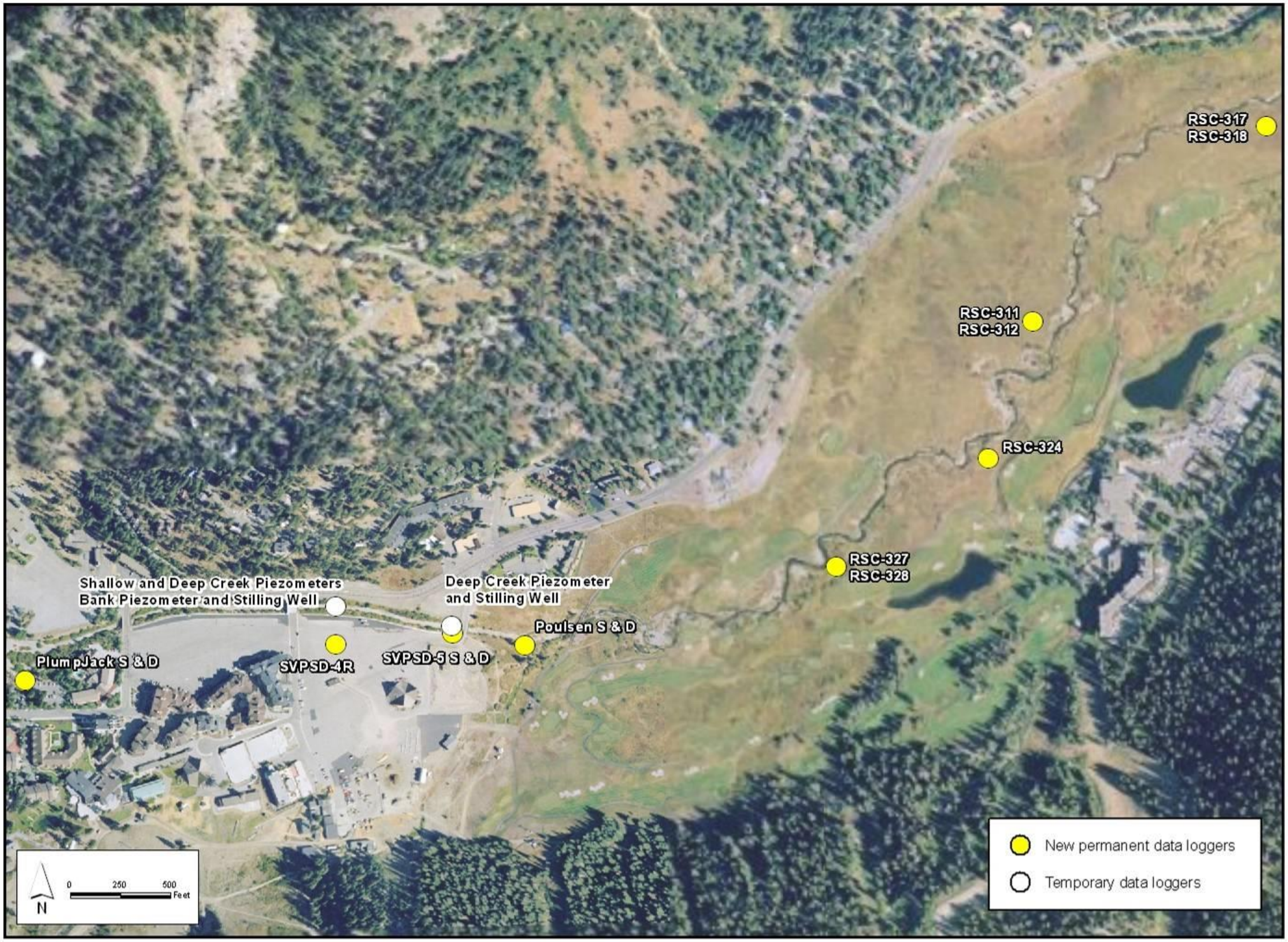


Figure 6: Locations of New Data Loggers

The equipment installed in each well is shown in Table 4.

Table 4: Summary of Monitoring Equipment Installed in Wells

Well	Monitoring Equipment
RSC-312	10m Mini-Diver and DDC
RSC-318	10m Mini-Diver and DDC
RSC-328	10m Mini-Diver and DDC
RSC-324	10m Mini-Diver and DDC
RSC-311	10m Mini-Diver and DDC
RSC-317	10m Mini-Diver and DDC
RSC-327	10m Mini-Diver and DDC
Poulsen Shallow	10m Mini-Diver and DDC
Poulsen Deep	20m Mini-Diver and DDC
PlumpJack Shallow	20m Mini-Diver and DDC
PlumpJack Deep	20m Mini-Diver and DDC
SVPSD MW-5S	20m Mini-Diver and DDC
SVPSD MW-5D	20m Mini-Diver and DDC
SVPSD #4R	20m Mini-Diver and DDC

DDC = Diver Data Cable
10m = 10 meter range
20m = 20 meter range

2.4 TASK 4: AQUIFER TESTING

Two constant rate aquifer tests were conducted in accordance with the modified scope of work. Both tests were conducted on well SVPSD #2, which is SVPSD's lead pumping well.

The first aquifer test was conducted on well SVPSD #2 between June 23 and June 25, 2009. Squaw Creek was flowing during the test. A photo shoing the condition of Squaw Creek during the first test is shown in Figure 7.

The first test was run for 52 hours. During the test, well SVPSD 2 was pumped at an average rate of 319 gallons per minute. All other SVPSD wells were idle during the test. Water level data were collected at the following wells throughout the test:

- SVPSD #2
- SVPSD #4R
- SVPSD #1

- SVPSD MW-5S
- SVPSD MW-5D
- SVMWC #1
- Poulsen Well, Shallow
- Poulsen Well, Deep
- The four piezometers in Squaw Creek and the two stilling wells that measure surface water levels in Squaw Creek

The eighteen temperature data loggers discussed above were also monitored during the test.

Groundwater drawdown data were collected during the 52-hour test. Groundwater recovery data were collected for approximately three and a half hours after the end of the test. Recovery measurements were stopped when SVPSD needed to restart its wells to meet demand.

Graphs of the measured groundwater elevation data and pumping rate data collected during the first aquifer test are provided in Appendix G. The raw data collected during the test is included on the enclosed CD.

The second aquifer test was conducted between September 8 and September 10, 2010. Squaw Creek was dry during the test. There were scattered showers on September 8, but not enough to develop any standing water in Squaw Creek. A photo showing the condition of Squaw Creek during the test is shown on Figure 8.

The second aquifer test was run for 51 hours. During the test, well SVPSD#2 was pumped at an average rate of 303 gallons per minute. All other SVPSD wells were idle during the test. Wells that were monitored during the test included:

- Well SVPSD #2
- Well SVPSD #4R
- Well SVPSD #1
- Well SVPSD MW-5S
- Well SVPSD WM-5D
- Well SVMWC #1
- Poulsen Well, Shallow
- Poulsen Well, Deep
- Four well points that measure shallow groundwater levels beneath Squaw Creek.

The eighteen temperature data loggers discussed above were also monitored during the second aquifer test.

Groundwater drawdown data were collected during the 51-hour test. Groundwater recover data were collected for approximately four hours after the end of the test. Recovery measurements were stopped when SVPSD needed to restart its wells to meet demand.

Graphs of the measured groundwater elevation data and pumping rate data collected during the second aquifer test are provided in Appendix G. The raw data collected during the test is included on the enclosed CD.

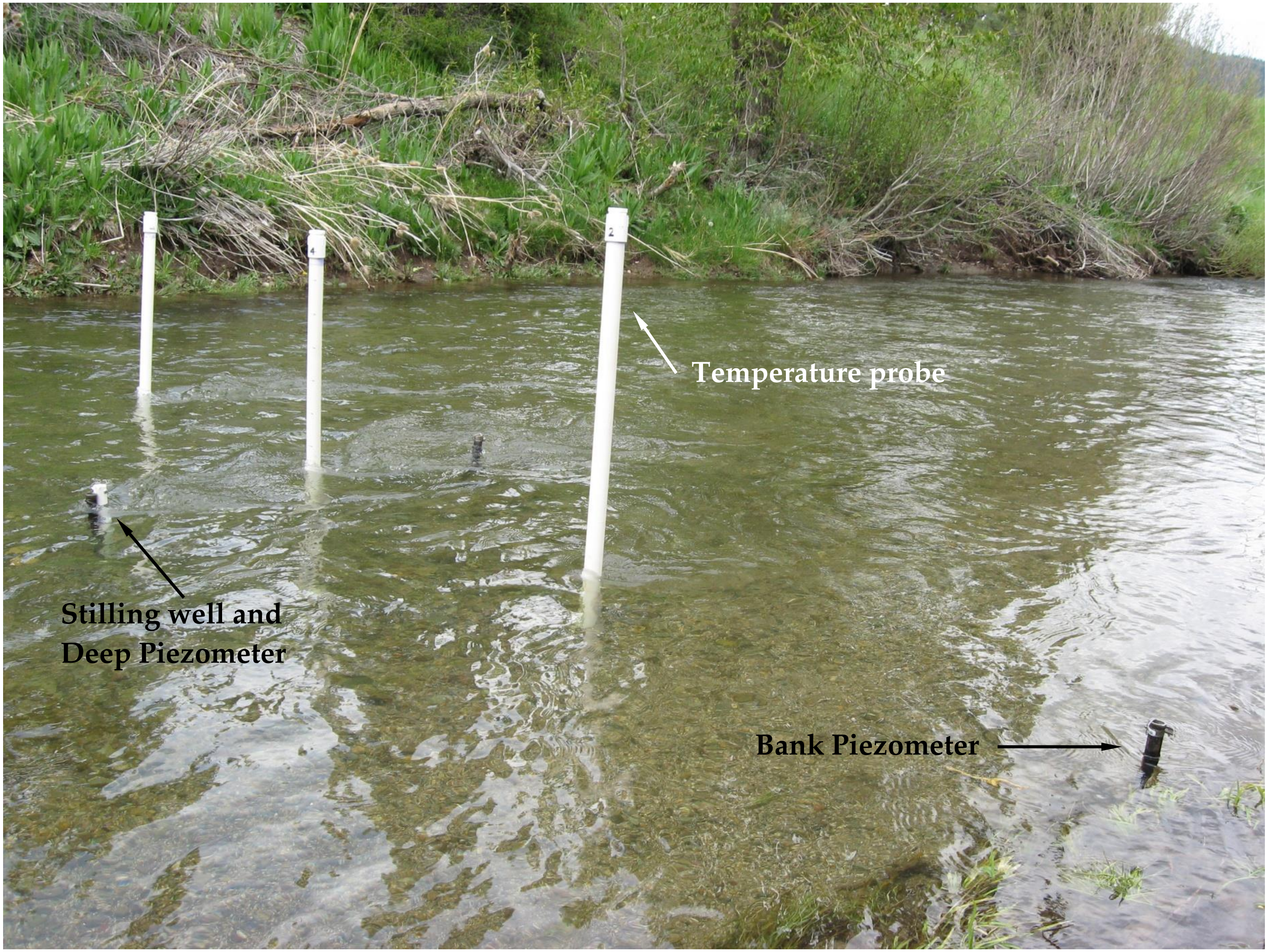


Figure 7: Monitoring Equipment in Flowing Squaw Creek during First Aquifer Test

Figure 8: Monitoring Equipment in Dry Squaw Creek during Second Aquifer Test

2.5 TASK 5: REPORTING

Reporting consisted of submitting quarterly reports and drafting this final report. Every quarterly report was prepared and submitted on time. The following quarterly reports were submitted:

- Fourth Quarter 2008; submitted in January 2009
- First Quarter 2009; submitted in April 2009
- Second Quarter 2009; submitted in July 2009
- Third Quarter 2009; submitted in October 2009
- Fourth Quarter 2009; submitted in January 2010
- First Quarter 2010; submitted in April 2010
- Second Quarter 2010; submitted in July 2010
- Third Quarter 2010; submitted in October 2010
- Fourth Quarter 2010; submitted in January 2011

Weather delays resulted in a longer project schedule than initially planned, and therefore more quarterly reports were produced than originally planned. The additional cost was minor because there was little to report during winter quarters, and therefore the quarterly reports were more brief than anticipated.

SECTION 3
COST INFORMATION

The Squaw Valley Creek/Aquifer Interaction Study has been completed within the original budget. Table 5 provides a breakdown of the original budget included in LGA Agreement 4600008205.

Table 5: Squaw Valley Creek/Aquifer Study Original Budget

Task	Description	Grant Amount
1	Pre-Construction Activities	$17,419
2	Drilling, Well Construction, and Development	$102,997
3	Equipping Monitoring Wells	$40,766
4	Aquifer Tests	$28,448
5	Reporting	$31,000
	Total	**$220,630**

Although the costs remain within the original project budget, some positive and negative cost variances occurred on individual tasks. Reasons for the variances between budgeted amounts and incurred costs for various tasks are detailed below.

TASK 1: PRE-CONSTRUCTION ACTIVITIES

Task 1 costs exceeded the budget largely due to efforts to incorporate recent technological advances in estimating stream/aquifer interactions. The project initially called for three monitoring well sites along the edge of Squaw Creek. Monitoring well locations at the Poulsen and PlumpJack Squaw Valley Inn sites remained as in the original plan. The monitoring well pair originally planned for the Squaw Valley Ski Corporation parking lot was replaced with the four temporary piezometers and six temperature probes in Squaw Creek. The extra costs incurred in Task 1 related to reconfiguring the monitoring plan and obtaining the necessary permissions and permits.

Additional costs were incurred in Task 1 to cover the second round of well permitting necessitated by the weather-caused delays. These additional permitting costs have been absorbed by SVPSD, and are not reflected in the modified budget.

TASK 2: DRILLING, WELL CONSTRUCTION, AND WELL DEVELOPMENT

Task 2 costs were slightly less than originally budgeted because we were able to combine field work on Tasks 2 and 3 into single field days. This allowed us to reduce the total time spent in the field, and bring in Task 2 under budget.

TASK 3: EQUIPPING MONITORING WELLS

Task 3 costs were less than originally budgeted because of savings on the cost of transducers and temperature data loggers. The cost of the 14 pressure transducers and associated data readers bought for the project was less than the cost originally estimated, when the project was being budgeted.

TASK 4: AQUIFER TESTS

Task 4 costs exceeded the original budget because the second aquifer test was delayed due to weather conditions in 2009. Money had been expended preparing for the second aquifer test in 2009 before it was delayed. This 2009 expenditure for the aborted aquifer test put this task over budget. The second aquifer test was run in 2010.

TASK 5: REPORTING

Task 5 costs were slightly less than originally budgeted because weather delays resulted in many quarters when there was little to report, and therefore the quarterly reports were more brief than anticipated.

Based on the above justifications, SVPSD requested that the individual task budgets be modified. The modification was requested as part of the third quarter 2010 quarterly report, submitted in October 2010. No change to the total grant amount was requested. DWR staff granted SVPSD’s budget modification request. Table 6 provides a breakdown of the final budget for LGA Agreement 4600008205.

Table 6: Squaw Valley Creek/Aquifer Study Final Budget

Task	Description	Grant Amount
1	Pre-Construction Activities	$25,465.97
2	Drilling, Well Construction, and Development	$101,636.05
3	Equipping Monitoring Wells	$37,395.91
4	Aquifer Tests	$32,184.58
5	Reporting	$23,947.49
	Total	**$220,630.00**

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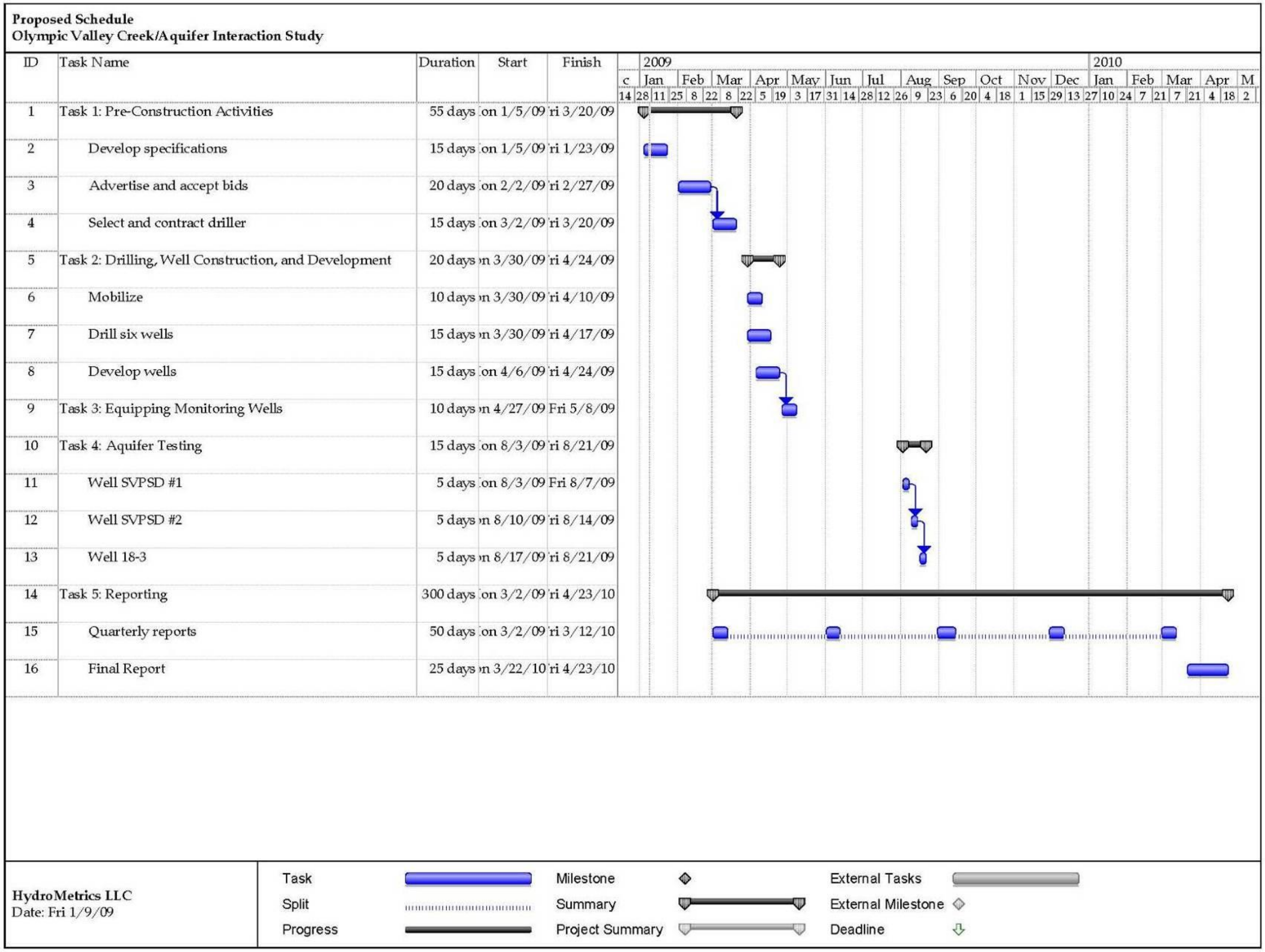
SECTION 4
SCHEDULE INFORMATION

Figure 9 shows the proposed schedule from the grant application. The schedule was updated every quarter based on progress made, weather delays, and scope changes. A revised schedule was included in every quarterly report. The final project schedule is shown in Figure 10.

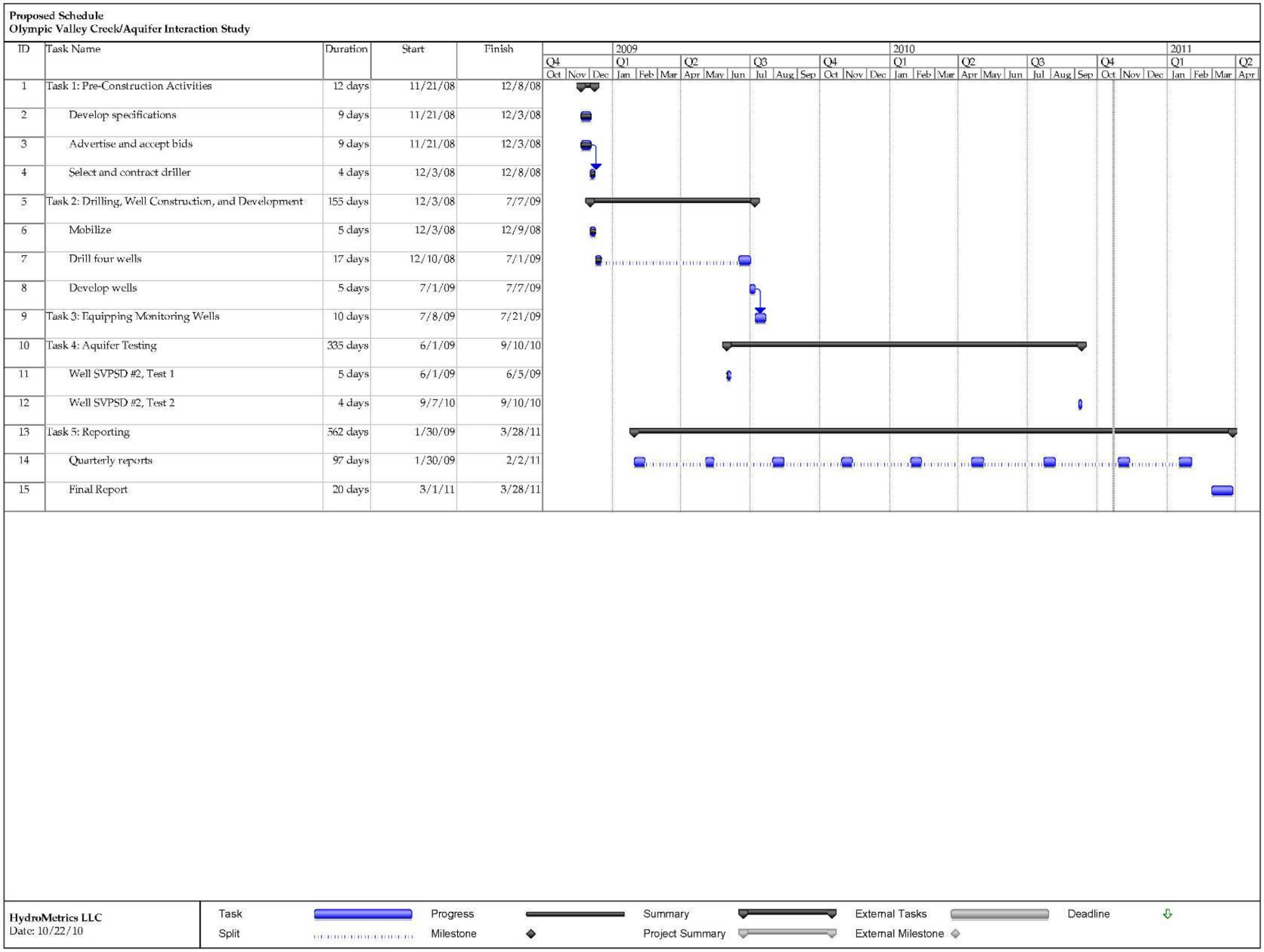


Proposed Schedule
Olympic Valley Creek/Aquifer Interaction Study

ID	Task Name	Duration	Start	Finish
1	Task 1: Pre-Construction Activities	55 days	on 1/5/09	ri 3/20/09
2	Develop specifications	15 days	on 1/5/09	ri 1/23/09
3	Advertise and accept bids	20 days	on 2/2/09	ri 2/27/09
4	Select and contract driller	15 days	on 3/2/09	ri 3/20/09
5	Task 2: Drilling, Well Construction, and Development	20 days	n 3/30/09	ri 4/24/09
6	Mobilize	10 days	n 3/30/09	ri 4/10/09
7	Drill six wells	15 days	n 3/30/09	ri 4/17/09
8	Develop wells	15 days	on 4/6/09	ri 4/24/09
9	Task 3: Equipping Monitoring Wells	10 days	n 4/27/09	Fri 5/8/09
10	Task 4: Aquifer Testing	15 days	on 8/3/09	ri 8/21/09
11	Well SVPSD #1	5 days	on 8/3/09	Fri 8/7/09
12	Well SVPSD #2	5 days	n 8/10/09	ri 8/14/09
13	Well 18-3	5 days	n 8/17/09	ri 8/21/09
14	Task 5: Reporting	300 days	on 3/2/09	ri 4/23/10
15	Quarterly reports	50 days	on 3/2/09	ri 3/12/10
16	Final Report	25 days	n 3/22/10	ri 4/23/10

HydroMetrics LLC
Date: Fri 1/9/09

Figure 9: Original Schedule



Proposed Schedule
Olympic Valley Creek/Aquifer Interaction Study

ID	Task Name	Duration	Start	Finish
1	Task 1: Pre-Construction Activities	12 days	11/21/08	12/8/08
2	Develop specifications	9 days	11/21/08	12/3/08
3	Advertise and accept bids	9 days	11/21/08	12/3/08
4	Select and contract driller	4 days	12/3/08	12/8/08
5	Task 2: Drilling, Well Construction, and Development	155 days	12/3/08	7/7/09
6	Mobilize	5 days	12/3/08	12/9/08
7	Drill four wells	17 days	12/10/08	7/1/09
8	Develop wells	5 days	7/1/09	7/7/09
9	Task 3: Equipping Monitoring Wells	10 days	7/8/09	7/21/09
10	Task 4: Aquifer Testing	335 days	6/1/09	9/10/10
11	Well SVPSD #2, Test 1	5 days	6/1/09	6/5/09
12	Well SVPSD #2, Test 2	4 days	9/7/10	9/10/10
13	Task 5: Reporting	562 days	1/30/09	3/28/11
14	Quarterly reports	97 days	1/30/09	2/2/11
15	Final Report	20 days	3/1/11	3/28/11

HydroMetrics LLC
Date: 10/22/10

Task	▬	Progress	▬	Summary	▬	External Tasks	▬	Deadline ⇩
Split	┈	Milestone	◆	Project Summary	▬	External Milestone ◇		

Figure 10: Final Revised Schedule

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SECTION 5
REFERENCES

Hatch, C.E., A.T. Fisher, J.S. Revenaugh, J. Constantz, and C. Ruehl, C., Quantifying surface water – ground water interactions using time series analysis of streambed thermal records: method development, *Water. Resour. Res.,* 42(10): 10.1029/2005WR004787.

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APPENDIX A: Well Permits

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Receipt #: 2614
Amt $1172
Check # 11073
By: JL
Date: 12/1/08
TO BE FILLED OUT BY ENVIRONMENTAL HEALTH DEPT

Placer County
Department of Health and Human Services
Environmental Health Services
3091 County Center Dr., Suite 180, Auburn CA 95603 (530) 745-2300
Tahoe Office: P O Box 1909, Tahoe City CA 96145 (530) 581-6240

UST/SOLID WASTE PROGRAMS
Permit Application for:
WELL CONSTRUCTION/DESTRUCTION

1. SR # 37706
2. SR # 37707
3. SR # 37708
4. SR # 37709
5. SR # ______
6. SR # ______
TO BE FILLED OUT BY ENV HLTH DEPT

WELL DESIGNATIONS AS SHOWN ON PLOT PLAN

1. Well ID MW-1a	2. Well ID MW-1b	3. Well ID MW-2a
4. Well ID MW-2b	5. Well ID	6. Well ID

Project Name MONITORING WELLS	Project Address SQUAW CREEK AND SQUAW LOOP	Location SQUAW VALLEY
Well Owner (project owner) SQUAW VALLEY PSD	Well Owner Address 305 SQUAW VALLEY RD.	Telephone 530-583-4692
Consultant's Name HYDROMETRICS	Consultant's Address 519 17TH STREET, SUITE 500, OAKLAND, CA	Telephone 510-903-0458 x301
Consultant's Registration P.G.		

If the well is to be located on ADJOINING OR NEARBY PROPERTY owned by another person, you must have that off-site property owner complete the acknowledgement below or attach copies of access agreements/encroachment permits.

ACKNOWLEDGEMENT OF OFF-SITE PROPERTY OWNER

I have read this application form and I approve of the construction of this proposed well

Offsite Well Address	
Property Owners Name and Address	Telephone
Property Owners Signature	Date

SUBMITTED SIGNATURE MUST BE ORIGINAL

Please indicate type of well:

☒ Groundwater Monitoring
☐ Water Extraction
☐ Vapor Extraction
☐ Gas Probe
☐ Exploratory Boring /Hydropunch/Geoprobe (indicate how many) ______
☐ Other (specify) ______
☐ Well Destruction
☐ Vadose/Lysimeter

PURPOSE OF WELL (if not explained in workplan) ______

Construction Specifications:

☒ Workplan Attached

☐ Workplan Previously Submitted - Workplan date ______
Prepared by ______

DRILLING CONTRACTOR
INFORMATION AND CERTIFICATION

Project Name: MONITORING WELLS

Drilling Company Name: WDC EXPLORATION & WELLS

C-57 License No. 283326

Drilling Company Address: 950 COUNTY RD 93B ZAMORA CA

Phone #(530) 662-2829

Fax # (530) 662-8052

A. NOTICE TO DRILLING CONTRACTOR: The Environmental Health Division shall be notified at least 48 hours in advance of drilling to schedule the REQUIRED inspections.

B. DRILLING CONTRACTOR'S WORKERS COMPENSATION DECLARATION
(**ONE** of the following three boxes must be completed)

☐ 1. A certified copy of Worker's Compensation Insurance is hereby furnished.

☒ 2. A current effective certificate is filed with Placer County Building Department or Environmental Health Division.

☐ 3. I certify that in performance of the work for which this permit is issued, I shall not employ any person in any manner so as to become subject to the California Worker's Compensation Act.

C. If well is located in or may otherwise obstruct public right-of-way, an encroachment permit is required.

D. Location and clearance of underground and aboveground utilities is the responsibility of the permittee.

I HAVE READ AND UNDERSTAND THE FOREGOING STATEMENTS (A, B & C) AND CERTIFY THAT ALL RELEVANT ACTIVITIES WILL BE PERFORMED IN COMPLIANCE WITH THESE STATEMENTS AND APPLICABLE CODES AND REGULATIONS. I HAVE SHOWN ALL EASEMENTS ON THE PROPERTY.

Well Drilling Contractor Signature ____________ Date 11/25/08

FOR OFFICIAL USE ONLY

☐ RWQCB Concurrence Received

This permit is issued subject to the following conditions. If these conditions are not satisfied, this approval/permit is null and void.

1. Monitoring wells shall be destroyed as required by the Environmental Health Division or R.W.Q. C. B.
2. Monitoring wells shall be capped and locked at all times except during sampling.
3. This permit expires one (1) year after date of issuance, but may be renewed for a fee if application is made PRIOR to expiration date.
4. All wells shall be constructed/destroyed pursuant to the standards set forth in the State of California Water Well Standards, Bulletin 74-90.

When signed by Placer County Environmental Health Division authorized representative, the application constitutes a PERMIT TO CONSTRUCT the subject well as herein specified:

Marty Goodman REHS

Permit Issued by:

12/2/08

Date

Seal Inspection Date: ____________

Comments: ____________

Receipt #: ________

Amt ________

Check # ________

By: ________

Date: ________

TO BE FILLED OUT BY ENVIRONMENTAL HEALTH DEPT

Placer County
Department of Health and Human Services
Environmental Health Services
3091 County Center Dr., Suite 180, Auburn CA 95603 (530) 745-2300
Tahoe Office: P O Box 1909, Tahoe City CA 96145 (530) 581-6240

UST/SOLID WASTE PROGRAMS
Permit Application for:
WELL CONSTRUCTION/DESTRUCTION

1. SR # ________
2. SR # ________
3. SR # ________
4. SR # ________
5. SR # ________
6. SR # ________

TO BE FILLED OUT BY ENV HLTH DEPT

WELL DESIGNATIONS AS SHOWN ON PLOT PLAN

1. Well ID: Plumpjack Deep	2. Well ID	3. Well ID
4. Well ID	5. Well ID	6. Well ID

Project Name: Squaw Valley Stream/ Aquifer Interaction Study	Project Address: 1920 Squaw Valley Road, Olympic Valley, CA, 96146	Location: Weste Parking Lot
Well Owner (project owner): Squaw Valley Public Service District	Well Owner Address: 305 Squaw Valley Road Olympic Valley, CA, 96146	Telephone: (530) 583-4692
Consultant's Name: HydroMetrics Water Resources Inc.	Consultant's Address: 519 17th Street, Suite 500 Oakland, CA 94612	Telephone: (510) 903-0458
Consultant's Registration: PG#6044		

If the well is to be located on ADJOINING OR NEARBY PROPERTY owned by another person, you must have that off-site property owner complete the acknowledgement below or attach copies of access agreements/encroachment permits.

ACKNOWLEDGEMENT OF OFF-SITE PROPERTY OWNER

I have read this application form and I approve of the construction of this proposed well

Offsite Well Address 1920 Squaw Valley Road, Olympic Valley, Ca 96146	
Property Owners Name and Address Plumpjack Squaw Valley Inn, 1920 Squaw Valley Road, Olympic Valley, CA 96146	Telephone (530) 583-1169
Property Owners Signature	Date 5/11/2010

SUBMITTED SIGNATURE MUST BE ORIGINAL

Please indicate type of well:

X Groundwater Monitoring

☐ Water Extraction

☐ Vapor Extraction

☐ Gas Probe

☐ Exploratory Boring /Hydropunch/Geoprobe (indicate how many) ________

☐ Other (specify) ________

☐ Well Destruction

☐ Vadose/Lysimeter

PURPOSE OF WELL (if not explained in workplan): Collect groundwater levels to compare with water levels in Squaw Creek.

Construction Specifications:

X Workplan Attached

☐ Workplan Previously Submitted - Workplan date ________
Prepared by ________

DRILLING CONTRACTOR
INFORMATION AND CERTIFICATION

Project Name: Squaw Valley Creek/Aquifer Interaction Study
Drilling Company Name: Boart Longyear
C-57 License No. 694686
Drilling Company Address: 1333 W. 9th Street, Upland, CA, 91786
Phone #(909) 946-1605
Fax # (909) 946-1608

A. **NOTICE TO DRILLING CONTRACTOR: The Environmental Health Division shall be notified at least 48 hours in advance of drilling to schedule the REQUIRED inspections.**

B. **DRILLING CONTRACTOR'S WORKERS COMPENSATION DECLARATION**
(ONE of the following three boxes must be completed)

☒ 1. A certified copy of Worker's Compensation Insurance is hereby furnished.

☐ 2. A current effective certificate is filed with Placer County Building Department or Environmental Health Division.

☐ 3. I certify that in performance of the work for which this permit is issued, I shall not employ any person in any manner so as to become subject to the California Worker's Compensation Act.

C. If well is located in or may otherwise obstruct public right-of-way, an encroachment permit is required.

D. Location and clearance of underground and aboveground utilities is the responsibility of the permittee.

I HAVE READ AND UNDERSTAND THE FOREGOING STATEMENTS (A, B & C) AND CERTIFY THAT ALL RELEVANT ACTIVITIES WILL BE PERFORMED IN COMPLIANCE WITH THESE STATEMENTS AND APPLICABLE CODES AND REGULATIONS. I HAVE SHOWN ALL EASEMENTS ON THE PROPERTY.

Well Drilling Contractor Signature Date 4-27-10

FOR OFFICIAL USE ONLY

☐ RWQCB Concurrence Received

This permit is issued subject to the following conditions. If these conditions are not satisfied, this approval/permit is null and void.

1. Monitoring wells shall be destroyed as required by the Environmental Health Division or R.W.Q.C.B.
2. Monitoring wells shall be capped and locked at all times except during sampling.
3. This permit expires one (1) year after date of issuance, but may be renewed for a fee if application is made PRIOR to expiration date.
4. All wells shall be constructed/destroyed pursuant to the standards set forth in the State of California Water Well Standards, Bulletin 74-90.

When signed by Placer County Environmental Health Division authorized representative, the application constitutes a PERMIT TO CONSTRUCT the subject well as herein specified:

Permit Issued by: 5·11·10 Date

Seal Inspection Date: Comments:

APPENDIX B: Well Specifications

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SCOPE OF WORK

PART 1 GENERAL

1.1 SUMMARY

A. Section includes summary of Work including:
   2. Work Covered By Contract Documents
   3. Bid Items and Alternates
   4. Mobilization, Demobilization, and Cleanup
   5. Borehole Drilling
   6. Monitoring Well Materials
   7. Monitoring Well Construction
   8. Monitoring Well Development
   9. Work Days and Hours
   10. Noise
   11. Standby Time and Downtime
   12. Lost Holes
   13. Depth of Well
   14. Cooperation of Contractor and Coordination with Other Work
   15. Maintenance, Product Handling, and Protection
   16. Contractor Use of Premises
   17. Damage to Existing Property
   18. Laydown/Staging Area
   19. Standards, Specifications and Codes
   20. Permits
   21. Unfavorable Construction Conditions
   22. Protection of Water Quality
   23. Construction Site Access
   24. Site Maintenance
   25. Final Clean Up
   26. Daily Job Report
   27. Site Administration

1.2 WORK COVERED BY CONTRACT DOCUMENTS

A. Work comprises drilling, developing, completing, and sampling four monitoring wells, two will be approximately 130 feet deep and two will be approximately 35 feet deep. The wells will be located in Squaw Valley (Olympic Valley), California.

B. Furnish all labor, materials, equipment, services, permits, temporary controls and construction facilities, and all general conditions, seismic requirements, general requirements and incidentals required to complete the Work in its entirety as described in the Contract Documents. The Work includes, but is not necessarily limited to the following:
   1. Monitoring well construction, including, but not limited to:
      a. Drilling four eight-inch (8”) nominal diameter boreholes. The depths specified in the bid documents are to be used for bid purposes only.
      b. Installing a 2-inch diameter PVC well in each of the four boreholes. The well slot sizes and screen lengths described in these bid documents and shown on Figure 1 are based on anticipated subsurface conditions. If field conditions require a variation from the slot sizes, the Contractor shall make substitutions at no additional cost to the Owner. If field conditions require a variation in the amount of screen or casing, the Contractor will be reimbursed for the actual footage used based on the unit costs bid.

        c. Providing and installing all appropriate fill materials shown in Figure 1. The fill materials described in these bid documents and shown on Figure 1 are based on the Districts estimate of anticipated subsurface conditions. If field conditions require a substitution of fill material, the bidder shall provide such material at no additional cost to the District.
        d. Keeping a daily record of work progress, crew present, and equipment and materials used.
        e. Installing monument surface completions at two of the wells with lockable caps on the protective casings.
        f. Installing flush mounted surface completions at two of the wells.
        g. Developing the completed well screens by pumping and surging.
        h. Separating drill cuttings, development sediments, and other solids from associated liquids, and properly disposing of them. Providing for the settlement or filtration and transport of development water to a discharge point as approved by the Geologist.
        i. Restoring the well site(s) to its original condition.
        j. Furnishing daily records to the Geologist.
        k. Furnishing completed well logs to the Geologist.
    2. The Contractor is required to contain liquid waste material(s) in containers provided by contractor until the liquids can be disposed of properly.
    3. It is Contractor's responsibility to properly dispose of all drilling mud, cuttings, and wastewater and to meet all state and local discharge requirements. The Contractor should provide an adequate means of separating gravel, sand, and silt from the discharge water stream. The Contractor may employ any means to achieve this, such as the use of settlement or temporary filtration for enhancing settlement of suspended sediment from the discharge stream.

C. The Work of this Contract includes work covered by unit prices.
D. Contractor's use of the premises for Work and storage is limited to the area approved of by the Geologist or other Owner's representative.
E. Contractor shall be solely responsible for providing any and all utilities (including without limitation electricity, water, gas, etc.) needed to complete the Work at the Site. District shall provide water source location(s) and necessary back-flow and metering equipment.

1.3 BID ITEMS AND ALTERNATES

A. Any Bid Item may be deleted from the Work and Contract Sum, in total or in part, prior to or after award of Contract without compensation in any form or adjustment of other Bid Items or prices therefore.
B. Payment of all items is subject to provisions of Contract Documents.
C. For all Bid Items, furnish and install all work indicated and described in Specifications and all other Contract Documents. Work and requirements applicable to each individual Bid Item, or unit of Work, shall be deemed incorporated into the description of each Bid Item (whether Lump Sum, or Unit Price).

1.4 MOBILIZATION, DEMOBILIZATION, AND CLEANUP

A. This section covers the Work necessary to move in and move out personnel and equipment. Mobilization and demobilization includes, but is not limited to, setting up and removing drill rigs, temporary facilities and utilities, preparing the site for construction of the well, and cleaning up the site upon completion.
B. Contractor shall provide all temporary and permanent materials and equipment required to accomplish the Work as specified.
C. Owner shall obtain permission for site access.
D. Workmanship:
    1. Contractor shall set up drilling and related other equipment within the area designated by the Geologist.
    2. The location of the monitoring well shall be determined by the Geologist but generally as shown on the attached map.

E. Construction Layout:
   1. Contractor shall set up construction facilities in a neat and orderly manner within designated areas. Contractor shall accomplish all required Work in accordance with applicable portions of these Specifications.
   2. Site conditions encountered that are not shown on the Drawings, or could not have been foreseen by visual inspection of the Site prior to bidding, should be immediately brought to the attention of the Geologist. The Geologist will make a determination for proceeding with the Work.

F. Contamination Precautions and Disposal of Material:
   1. Contractor, and its subcontractors, subconsultants, agents and employees, shall avoid contaminating the Project area. Contractor, and its subcontractors, subconsultants, agents and employees, shall not dump waste oil, rubbish, or other similar materials on the ground. All equipment leaks must be contained and not permitted to contaminate the Site, well, or discharge to storm drains.
   2. The Contractor is required to cover all work areas with tarps or plastic sheeting to prevent spilling cuttings, oil, waste, or soil on the snow.
   3. Contractor shall have proper absorbent materials onsite at all times to clean up any equipment leaks or spills to avoid contamination of the Site, well, or discharge to storm drains.
   4. Contractor shall be responsible for properly containing or disposing of all water, cuttings, sediments, and any drilling mud produced during drilling and development of the well. Disposal method and location must be approved by the Geologist.
   5. Owner shall provide discharge locations for clean, silt-free fluids.

G. Cleanup of Construction Areas:
   1. Upon completion and acceptance of the monitoring wells, Contractor shall remove from the Site the drill rig and related equipment, all debris, unused materials, and other miscellaneous items resulting from or used in the Work.
   2. Contractor shall restore the Site and associated facilities as nearly as possible to their original condition to the satisfaction of the Owner.

1.5 BOREHOLE DRILLING

A. Equipment: All equipment shall be the proper type and shall be in good condition to assure that the Work can proceed without interruption and that the drilling of a plumb and straight boring results.

B. The driller shall collect cuttings samples for lithologic logging every 5 feet in the boreholes. The Geologist will supply bags for the samples collected by the driller.

1.6 MONITORING WELL MATERIALS

A. The use of a specific manufacturer's name and/or model or catalog number is for the purpose of establishing the standard of quality and desired general configuration only.

B. PVC Well Casings:
   1. The PVC well casings shall be new, two-inches (2") inside diameter, and fabricated in lengths not less than twenty feet (20'), except where a shorter section of casing is better suited for the total depth or surface completion.
   2. All well casing shall be Schedule 40 PVC and shall be flush threaded (ASTM F480).

C. PVC Well Screen:
   1. The PVC well screens shall be two-inches (2") inside diameter.
   2. The well screens shall be made of Schedule 40 PVC and have machined slots perpendicular to the axis. Well screen sections shall have ASTM F480 flush threads.
   3. The screen slot size shall be 0.020 inches. The Geologist may modify this based on observed field conditions.
   4. Screen lengths will be determined by the Geologist, based on conditions observed during drilling. For bidding purposes, 30 feet of screen will be installed in each of the deep wells and 20 feet of screen will be installed in each of the shallow wells.

D. Well Centralizers:

   1. Well centralizers shall be installed at the bottom of the well screen, and at approximately 20 foot intervals along the well casing.
   2. The centralizers shall be not more than 12 inches long. Casing centralizers shall be designed to allow the proper passage and distribution of sealing material around the casing(s) within the interval(s) to be sealed.

E. Gravel Pack:
   1. Gravel for packing the monitoring wells shall be Lone Star Monterey sand, or approved equal, and be of high uniformity. The gravel pack shall be Lonestar #3 or equivalent approved by Geologist. The type, size, gradation, and uniformity of gravel may be modified by the Geologist depending on field conditions.
   2. All gravel pack material shall be hard, water-worn, and washed clean of silt, sand, dirt, and foreign matter. Crushed gravel will not be accepted. The specific gravity of the material shall be not less than 2.5 as determined by ASTM Designation D854.

F. Bentonite:
   1. Bentonite used for this annular transition seal shall consist of medium Enviroplug®, or approved equivalent, and shall be placed in accordance with the manufacturer’s recommendations.

G. Grout:
   1. Grout used to construct the annular seal shall be neat cement or a ten sack sand-cement grout mixture. The cement shall meet the requirements, including the latest revisions, of ASTM C150 Standard Specification for Portland Cement Type I, or an approved equivalent. Any additives shall meet the requirements, including the latest revisions, of ASTM C494 Standard Specifications for Chemical Admixtures for Concrete. Additives must be approved by the Geologist. The sand shall be washed clean prior to mixture.

H. Well Monument Completions
   1. Monitoring wells completed with monument completions shall extend approximately 18 inches above grade.
   2. The well will be completed with a 6-inch diameter (6”) steel protective monument with locking lid. The well and steel monument shall be completed with a concrete pad, so installed as to prevent damage to the well, crowned to drain water away from the monitoring well, and permit easy access for instrumentation, monitoring, or sampling. Upon completion of the well, the Contractor shall install a water-tight locking well cap at the top each monitoring well.

I. Well Flush Surface Completions
   1. Monitoring wells completed with flush surface completions shall be terminated below ground surface (below grade) and covered with vault securely cemented into place. The vault shall be completed ½ to 1 inches above ground surface to prevent ponding around the well. The traffic box shall be so installed as to permit easy access for instrumentation, monitoring, or sampling. A sufficient number of weep holes or a gravel drain shall be placed in the well box subgrade so that any condensation or liquid is readily drained from the box, thus preventing ponding. The finished length of each monitoring well casing shall extend from the top of the screen to no more than 5 inches below ground surface. Upon completion of the well, the Contractor shall install a water-tight locking well cap at the top each monitoring well.

J. Water and Sewer:
   1. Owner will identify a source of water for the driller, as well as necessary back-flow and metering equipment.
   2. Contractor shall make arrangements for transporting or piping water from the source to the drill site.
   3. Contractor is responsible for any costs of purchasing water from the utility district.
   4. Owner will identify a location for disposal of clean, silt-free water.

5. Contractor may be able to make arrangements with the Tahoe Truckee Sanitation Agency (TTSA) for waste discharge to sewer. Contractor is responsible for obtaining and adhering to any permits required by the TTSA.

1.7 MONITORING WELL CONSTRUCTION

A. General:
   1. Equipment: All equipment shall be the proper type and shall be in good condition to assure that the Work can proceed without interruption and that the drilling of a plumb and straight well results. For bidding purposes, drilling equipment shall be of sufficient size, strength, and design to maintain plumbness and alignment in drilling an 8-inch diameter boring to set the well to a maximum depth of 200 feet.
   2. Wells will be constructed in accordance with the applicable requirements of California Department of Water Resources Bulletins 74-81 and 74-90.
   3. Logging and Records: Contractor shall furnish the Geologist with a written daily log of the Work. Information supplied shall include, at a minimum, accurate depth, thickness, and nature of the strata penetrated. Drilling rates, water levels, and other information may also be requested by the Geologist. Progress on all phases of the Work shall also be reported. This shall include, but not be limited to, the drilling operations, the placement of the casing, screen, gravel pack and annular seal, and development records. These daily records should indicate all quantities of unit price pay items and should be signed daily by the Contractor and a representative of the Geologist.

B. Installation of Casing and Screen:
   1. Contractor shall install well casing and screen within 72 hours of reaching the total depth of the borehole. Casing and screen lengths and locations will be determined by the Geologist, based on the results of the sampling of the borehole.
   2. Contractor shall be responsible for supporting and anchoring the well casing in such a way as to hold it in place during the placement of gravel and annular seals, during development, and when the well is completed. The bottom of the casing shall be at a sufficient distance above the bottom of the hole to ensure that none of the weight of the casing is supported from the bottom of the hole.
   3. Contractor shall place centralizers at intervals along the length of the casing to ensure a minimum separation of 2 inches between the well casing and the borehole wall. The centralizers shall not be placed closer than 10 feet apart along a casing string within the interval to be sealed, unless otherwise approved by the Geologist.
   4. A PVC end cap shall be installed at the bottom of the well using a threaded connection.
   5. If, for any reason, the casings cannot be landed in the correct position or at a depth acceptable to the Geologist, the Contractor shall construct another well immediately adjacent to the original location and complete this well in accordance with the Specifications at no additional cost to the Owner. The abandoned hole shall be sealed in accordance with local and State laws pertaining to proper well abandonment.
   6. Any casing and/or screen that fails, collapses, or separates shall be repaired or replaced, or a new well drilled, as approved by the Geologist, at Contractor’s sole expense.

C. Installation of Gravel Packs:
   1. The gravel packs shall be placed in the well bore annulus using a feed line, or tremie pipe in accordance with AWWA A100-90, Section 6.7. Gravel pack shall be placed to the levels shown on Figure 1, or as specified by the Geologist. The gravel shall be placed through a feed line, or tremie pipe, that extends to the bottom of the casing annulus. The feed line shall be gradually withdrawn as the gravel pack is placed. Care shall be exercised to avoid bridging of the gravel pack. The placement shall proceed without interruption until completion.
   2. Should the borehole not take the calculated volume of gravel, with allowances for normal losses and settling, the Geologist will have cause to reject the well.

D. Installation of Bentonite Seals:

1. Bentonite seals shall be placed in the borehole through the feed line or tremie pipe from the in a manner that will ensure that there are no gaps or bridging in the seal. Bentonite shall be placed to the levels shown on Figure 1, or as specified by the Geologist.
2. The Contractor will sound the seal to verify the location of the top of the seal. No additional work will be performed until the depth to the top of the seal has been accurately determined by sounding.

E. Installation of Annular Grout Seal:
   1. After the bentonite seal has been placed to the satisfaction of the Geologist, an annular grout seal shall be placed from the top of the bentonite seal to the ground surface.
   2. The grout shall be installed by the positive displacement method. The grout shall be installed through a tremie pipe from the bottom of the annulus upward. The tremie pipe may be slowly raised as the grout is placed, however the discharge end of the tremie pipe shall be submerged in the emplaced grout at all times until grouting is completed.
   3. The rate of grout placement shall not exceed 1-1/2 feet per minute, as measured by a sounding line, and placement shall proceed in a single operation, without interruption until completion, unless approved by the Geologist.
   4. Once the grouting operation is complete, no further work shall be performed on the well for a minimum of twenty-four (24) hours. No standby time will be paid while cement is setting.

F. Installation of Bottom Plug
   1. If the borehole is drilled deeper than the well depth as determined by the Geologist, Contractor shall fill the borehole with grout to no more than 10 feet below and no less than 5 feet below the bottom of the well. The grout shall be allowed to set for no less than 24 hours prior to well installation within the borehole, unless approved by the Geologist.
   2. The method of grout placement shall be by pumping the grout through a tremie pipe from the bottom of the annulus upward. The rate of grout placement shall not exceed 1-1/2 feet per minute, as measured by a sounding line, and placement shall proceed without interruption until completion, unless approved by the Geologist.

1.8 MONITORING WELL DEVELOPMENT

A. General: After at least 24 hours following emplacement of the grout seal, Contractor shall begin developing the monitoring well in conformance with the following Specifications. The Contractor shall furnish all materials, equipment, and labor required to develop the well.

B. Pump/Airlift development
   1. The well shall be developed with a submersible pump or by airlifting.
   2. Development with a submersible pump shall proceed over each 10-foot section of screen. The pump shall initially be installed to the top of the uppermost screen. Water shall be pumped from this screen for a minimum of 20-minutes, or until water produced is free from sediment and clear to the unaided eye. The pump will then be lowered 10 feet, and development will continue.
   3. Development by air lifting shall be done in a manner that prevents air entrainment in the surrounding aquifer. If possible, the air line shall be placed in the well inside an outer eductor tube to prevent air entrainment. The bottom of the air line shall be at least 10 feet above the bottom of the eductor tube. If use of an eductor tube is not possible, the bottom of the air line will remain at least 10 feet above the top of the well screen at all times.
   4. The well will be pumped or air lifted until the water produced by the well is free from sediment.

C. Completion of Development:
   1. The well shall be considered thoroughly developed when the water produced is clear to the unaided eye or approved by the Geologist.

1.9 WORK DAYS AND HOURS

A. Work or activity associated with the wells, including, but not limited to, mobilization on site, well drilling, well construction, well development, and site cleanup shall be limited to hours from 7:00 a.m. to 7:00 p.m., local time, Monday through Saturday. Work or activity not limited to these hours shall include well casing, gravel pack, and annular seal installation if this work can be done without excessive noise or violating any permit restrictions.

B. The Contractor shall notify District at least two days in advance of scheduling any Work.

1.10 NOISE

Contractor shall comply with all local noise ordinances. At the Geologist's request, Contractor shall provide proper noise abatement controls, such as sound dampening blankets, at a height sufficient to shield nearby buildings from noise generated during drilling, well development, and casing, gravel pack and seal installation. Contractor shall be compensated for the additional cost of noise control by Owner.

1.11 STANDBY TIME AND DOWNTIME

A. During the progress of drilling and/or testing operations, and well development it may be necessary for the Geologist to perform work that will require the drilling crew and equipment to stand idle. In such events, the Geologist will request Contractor to furnish such assistance or to cease operations and shall state the anticipated extent of duration thereof. Contractor shall promptly furnish such assistance and cease operations.

   1. Standby time shall be paid for any portion of a normal workday when the Geologist orders work to cease or when other activities at the site dictate shutdown as approved by the Owner's Representative.
   2. Payment for actual hours of standby time will be made at the unit bid price per hour stated in Contractor's Bid.

B. Downtime shall mean that time, other than standby time, during which drilling, developing or sampling could occur but does not. Downtime includes times when machinery is broken down, materials or equipment are not available, weather prevents activity, or Contractor elects not to drill. All downtime shall be at the sole expense of Contractor.

1.12 LOST HOLES

A. Holes Abandoned for Cause: If the Geologist determines that for reasons beyond the control of Contractor it is necessary to stop drilling, or if for reasons beyond the control of Contractor the hole is lost before the objective or desired depth is reached and further attempts to save or complete the hole are not practical, the hole will be ordered abandoned for cause. Contractor shall fill and plug the hole according to the most restrictive city, county, state and/or federal regulations. Contractor will be reimbursed for the footage drilled and other operations, and for well destruction/hole abandonment labor and materials.

B. Defective Holes: If the Geologist determines that the hole is lost due to negligence, incompetence, or malpractice on the part of Contractor or Contractor's personnel, agents, subcontractors, or consultants, or to the use of defective or unsuitable equipment, the Geologist will immediately notify Contractor in writing of his/her decision and order the hole abandoned. If a hole does not meet the requirements set forth herein, or if Contractor fails to drill a hole to the depth specified by the Geologist within the scope of the Contract, the hole will be declared abandoned. Contractor, at its own expense, shall fill and plug the hole according to the most restrictive city, county, state and/or federal regulations. Contractor shall drill a new hole at an alternate site in the immediate area approved by the Geologist. Contractor will not be paid for any footage drilled or for other operations performed in any hole abandoned because of defects.

1.13 DEPTH OF WELLS

The total depth of the completed wells will be determined by the Geologist after examination of the drill cuttings. For the purposes of bidding, it is expected that the total depth of two of the completed wells shall be 130 feet and two of the completed wells shall be 40 feet.

1.14 COOPERATION OF CONTRACTOR AND COORDINATION WITH OTHER WORK

A. Coordinate with District and any District forces, or other contractors and forces, as required by the General Conditions in the contract.
B. Coordinate and constantly review Contract Documents, submittals, changes, and prepare overlay drawings as necessary to avoid conflicts, errors, omissions and untimely construction.
C. Contractor shall be responsible to give the Geologist 48-hour minimum advance notice prior to performance of specific operations as follows:
   1. Mobilization of equipment to the Site.
   2. Starting drilling operations at the Site.
   3. Installation of bottom plug.
   4. Installation of well screen and casing.
   5. Placement of gravel pack and the annular grout seal.
   6. Development of the wells.

   These minimum advance notification requirements are based on the normal sequence and schedule of Work assuming no unusual delays. If delays or interruptions should occur, the Geologist shall be given as much advance notification as possible of the restart of Work on the Project.

1.15 MAINTENANCE, PRODUCT HANDLING, AND PROTECTION

A. Contractor shall transport, deliver, handle, and store materials and equipment at the Site in such a manner as to prevent the breakage, damage or intrusions of foreign matter or moisture, and otherwise to prevent damage.
B. Hazardous substance compliance: Contractor shall provide District with copies of the OSHA Material Safety Data Sheets (MSDS) for all products containing a hazardous substance, such as, but not limited to adhesives, paints, sealants, and the like.
C. Contractor shall remove all damaged or otherwise unsuitable material and equipment promptly from the Site.
D. Contractor shall protect all finished surfaces.
E. Cost of maintenance of systems and equipment prior to Final Acceptance will be considered as included in prices bid and no direct or additional payment will be made.

1.16 CONTRACTOR USE OF PREMISES

A. Contractor shall confine operations at Site to areas permitted by Contract Documents, permits, ordinances, and laws.
B. Contractor shall not unreasonably encumber Project Site with materials or equipment.
C. Contractor assumes full responsibility for protection and safekeeping of products stored on premises.
D. Contractor shall move any stored products that interfere with operations of District or other contractor.
E. Owner shall provide storage areas off the Site for drill rig and support equipment, material and supplies for well construction.

1.17 DAMAGE TO EXISTING PROPERTY

A. Throughout the period of construction, Contractor shall keep the work site free and clean of all rubbish and debris.
B. Protective barriers and other safety protection necessary to protect the public and workers shall be provided by Contractor.

C. Contractor shall notify District prior to commencement of the Work of any anticipated impacts to the landscaping or other aspects of the property.

D. Contractor shall be responsible for all damage to streets, roads, curbs, sidewalks, highways, shoulders, ditches, embankments, culverts, bridges, fences, walls, buildings, trees, landscape, or other public or private property, which may be caused by transporting equipment, materials, or workers to or from the Work. Contractor shall protect all existing structures and property from damage and shall provide bracing, shoring, or other work necessary for such protection.

E. In the event of damage to such property listed above, Contractor shall, at its own expense, immediately restore the property to a condition equal to its original condition and to the satisfaction of the Geologist, and at no additional cost to District.

1.18 LAYDOWN/STAGING AREA

A. Owner shall provide a suitable staging area for equipment not stored on Site. Contractor shall utilize the area for storage of all construction materials.

B. After completing the Work, the Contractor shall remove from the premises and Work areas all materials, tools, debris, and drill cuttings from the drilling and development operations. At the completion of the Work, Contractor shall clear Site of all materials and leave Site in a condition acceptable to the Geologist.

1.19 STANDARDS, SPECIFICATIONS AND CODES

A. The wells shall be constructed and abandoned in conformance with the State of California Water Well Standards as described in the Department of Water Resources (DWR) Bulletin No. 74-81 and amended in Bulletin 74-90. The requirements of District, as stipulated in the Drilling Permit, shall also be observed in construction of the wells. Contractor shall be responsible for filing well completion reports required by the State and District. A copy of each well completion report shall be provided to the owner.

B. In the case of conflicting local, state, or federal well standards, the wells and boreholes shall be constructed and abandoned in conformance with the most restrictive standards.

1.20 PERMITS

A. Contractor is responsible for obtaining and complying with conditions of all necessary permits that are required to complete this Contract including, but not limited to County drilling permits, waste discharge permits, or water disposal permits.

B. Contractor shall comply with all applicable conditions set forth in any permits obtained by District for this Project.

C. Contractor shall be responsible for all associated costs of permits, and such costs are to be included in the bid price. Such costs shall include, but are not limited to, any traffic control or noise abatement measures. District will apply and pay for any necessary encroachment permits.

D. Contractor shall promptly provide the Geologist with one copy of each permit, license and agreement obtained by the Contractor, necessary for compliance with this Contract.

E. Where requirements and conditions of permit differ from those of the Plans and Specifications, the more stringent requirements shall apply.

1.21 UNFAVORABLE CONSTRUCTION CONDITIONS

A. Well installation, development, and testing will take place during winter conditions, potentially over packed snow at high elevations (approximately 6,200 feet msl). Cold and snow or rain are possible, and Contractor must be able to work under such conditions.

B. During severe weather, melting snow, or other unsuitable construction conditions, Contractor shall confine its operations to Work which will not be affected adversely by such conditions. No portion of the Work shall be constructed under conditions which would affect adversely the quality or efficiency thereof, unless special means or precautions are taken by Contractor to perform the Work in a proper and satisfactory manner.

1.22 PROTECTION OF WATER QUALITY

A. Contractor shall, at all times, perform Work in such a manner as to prevent the introduction of contaminants into the wells or down storm drains. Contractor shall ensure that only groundwater of sufficiently low turbidity is allowed to discharge to the storm drains or other discharge points. Turbid groundwater must be filtered or allowed to sit long enough for the sediment to settle out before discharging to the sanitary sewer.

B. Contractor shall supply ample water storage containers to hold discharge water until it is clear enough for discharge.

1.23 CONSTRUCTION SITE ACCESS

A. Contractor shall conform to CAL/OSHA safety standards at all times.

B. Contractor shall perform all work with the access limits shown in the Contract Drawings or as directed by the Geologist and as follows:

1. Well Site: Drilling Equipment shall be set up within the area approved by the Geologist. Upon completion and acceptance of the Work, all equipment, unused materials, temporary facilities, and other miscellaneous items resulting from or used in the operations shall be removed. The well site shall be restored to its original ground configuration by filling any pits or trenches and leveling soil piles or ruts.
2. All Work Sites: All stored materials and equipment shall be removed from the Work Sites as part of demobilization upon completion of this Contract.

C. Contractor shall, at all times, limit access to the Site to necessary personnel only.

1.24 SITE MAINTENANCE

During the progress of Work, Contractor shall keep area used by Contractor’s forces in a neat, orderly and sanitary condition. Contractor shall dispose of refuse as often as directed or as may be necessary, so that at no time shall there be any accumulation of rubbish, excavated material or equipment that will cause an inconvenience to Work or the public.

1.25 FINAL CLEAN UP

A. On completion of Work, Contractor shall clean all portions of job site.

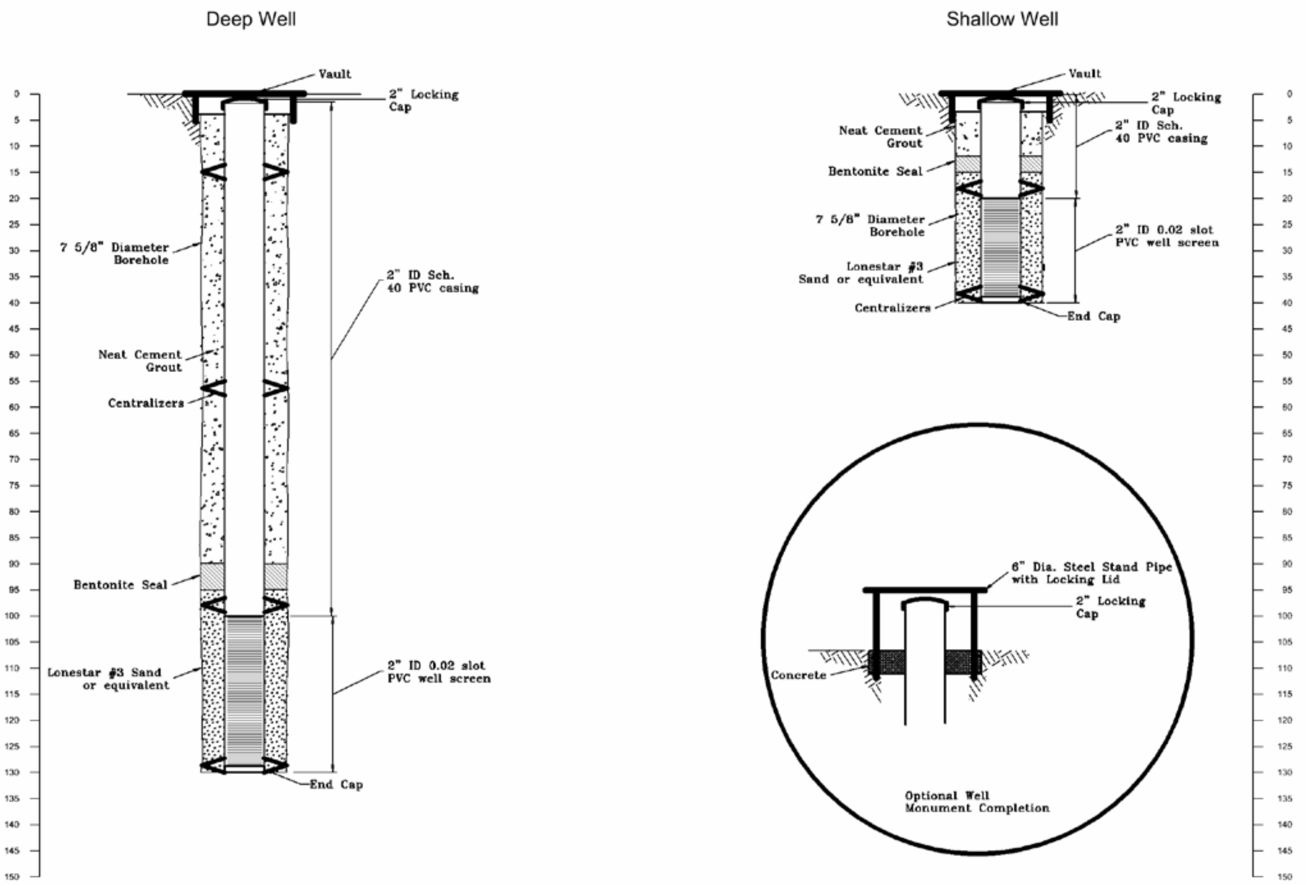
B. Care shall be taken to safeguard plants, shrubs or other improvements in the Work areas.

1.26 DAILY JOB REPORTS

Contractor shall maintain daily job reports recording all significant activity on the job, including the number of workers on Site, Work activities, equipment and materials used, problems encountered and delays. Contractor shall provide the daily job report to the Geologist for approval at the conclusion of each workday.

1.27 SITE ADMINISTRATION

Contractor shall be responsible for all areas of the Site used by it and by all Subcontractors in the performance of the Work. Contractor shall exert full control over the actions of all employees and other persons with respect to the use and preservation of property and existing facilities, except such controls as may be specifically reserved to District or others. Contractor shall have the right to exclude from the Site all persons who have no purpose related to the Work or its inspection, and may require all persons on the Site (except Owner’s employees) to observe the same regulations as Contractor requires of its employees.



Notes:

Drawing not to scale.

Completion details shown for information only. Depth of completion details may be modified based on field conditions. Surface completion is not to scale

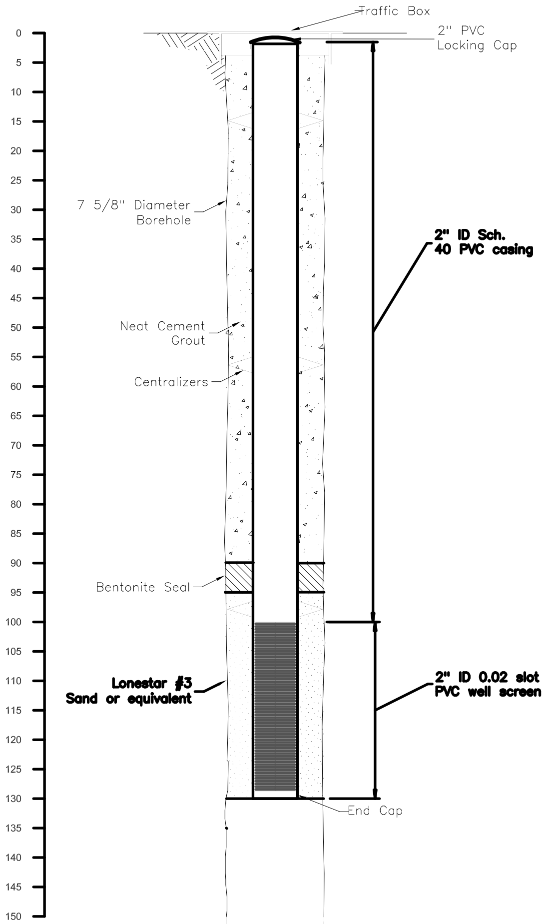
Figure 1

Proposed Well Construction Diagram
Monitoring Wells
Squaw Valley Public Serivce District
Placer County, CA

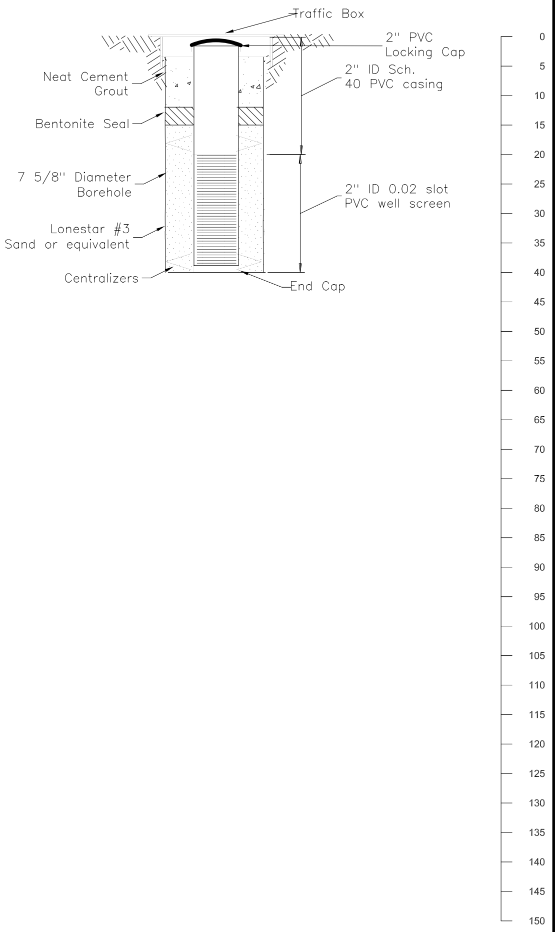
Date 11/24/08

HydroMetrics LLC

Deep Well



Shallow Well



Notes:

Drawing not to scale.

Completion details shown for information only. Depth of completion details may be modified based on field conditions. Surface completion is not to scale

Figure

Proposed Well Construction Diagram
Plumpjack Monitoring Wells
Squaw Valley Public Serivce District
Placer County, CA

Date 11/24/08

APPENDIX C: Well Logs

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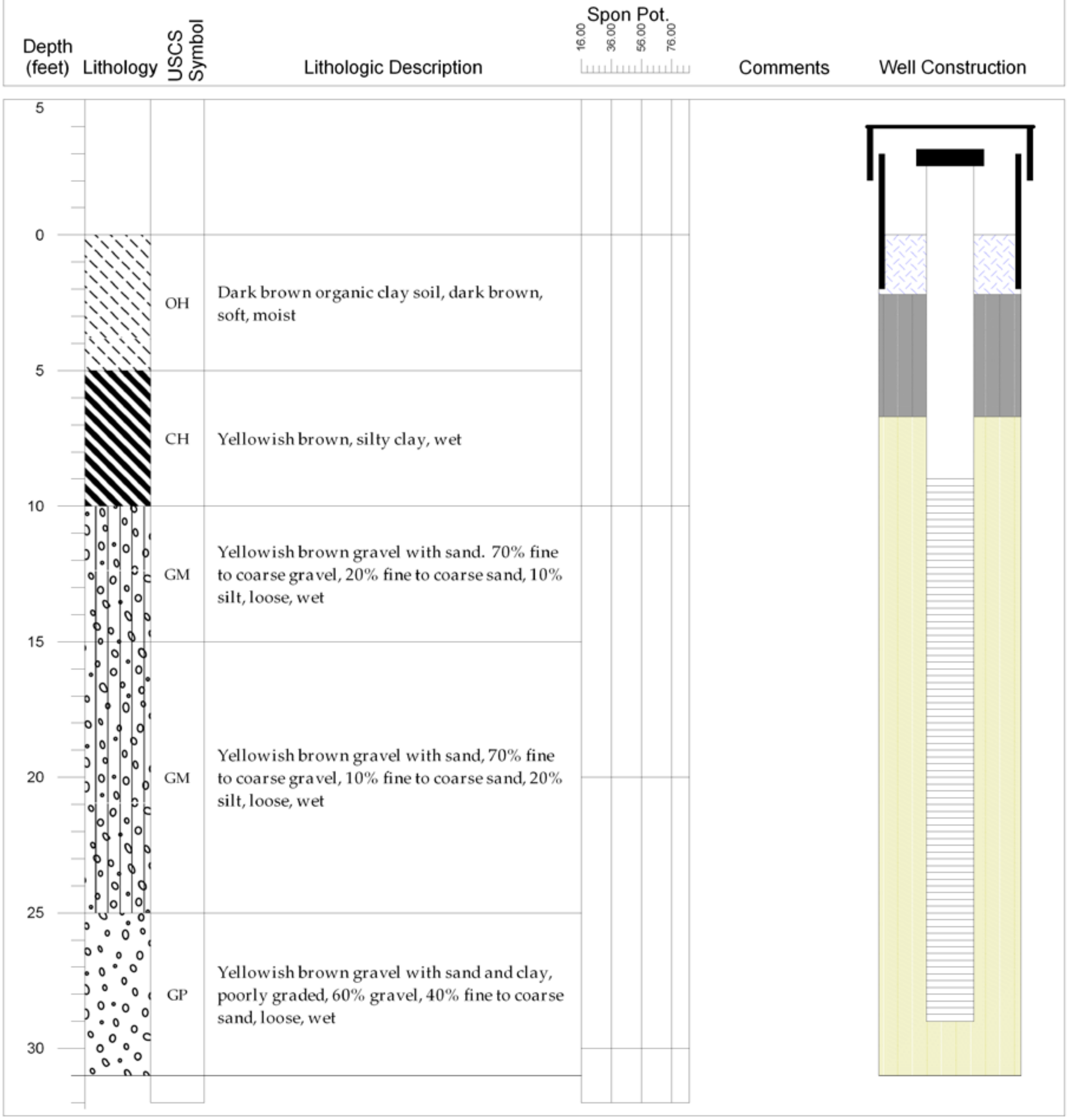
Hydro Metrics WRI

AQUIFER-STREAM INTERACTION

Squaw Valley Public Service District

Page 1 of 1

Poulsen-Shallow



Depth (feet)	USCS Symbol	Lithologic Description
0 - 5	OH	Dark brown organic clay soil, dark brown, soft, moist
5 - 10	CH	Yellowish brown, silty clay, wet
10 - 15	GM	Yellowish brown gravel with sand. 70% fine to coarse gravel, 20% fine to coarse sand, 10% silt, loose, wet
15 - 25	GM	Yellowish brown gravel with sand, 70% fine to coarse gravel, 10% fine to coarse sand, 20% silt, loose, wet
25 - 31	GP	Yellowish brown gravel with sand and clay, poorly graded, 60% gravel, 40% fine to coarse sand, loose, wet

Northing (Y): 2202919.646 Logged By: Dave van Brocklin
Easting (X): 7063618.962
Coordinate System: NAD83 CA State Plane Zone 2 (feet)
Ref. Point Elevation, ft amsl: 6192.31
Location:

Drilling Dates: 12/12/2008
Drilling Contractor: WDC Exploration & Wells
Drilling Method: Air Rotary
Total Drilled Depth, ft: 31

Fill Materials	
0 - 2.2	Neat Cement
2.2 - 6.7	Bentonite
6.7 - 31	Cemex #3

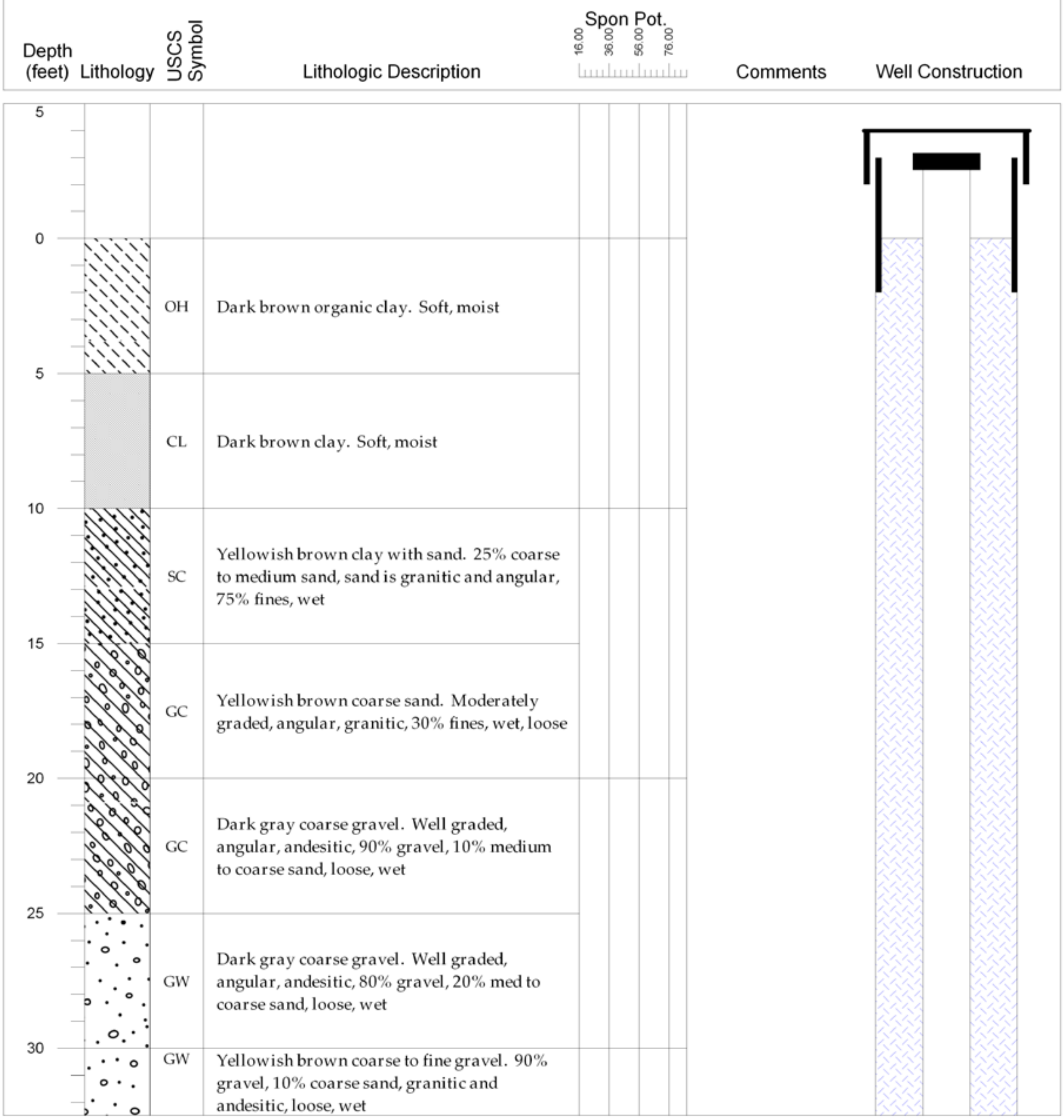
Depth, ft	Hole Diam., in.	Casing Diam., in.	Casing Material
-3 - 9	6	2	Sch. 40 PVC Blank
9 - 29	6	2	Sch. 40 PVC 0.02" Screen

HydroMetrics WRI

AQUIFER-STREAM INTERACTION

Squaw Valley Public Service District

Poulsen-Deep



Depth (feet)	Lithology	USCS Symbol	Lithologic Description
0–5		OH	Dark brown organic clay. Soft, moist
5–10		CL	Dark brown clay. Soft, moist
10–15		SC	Yellowish brown clay with sand. 25% coarse to medium sand, sand is granitic and angular, 75% fines, wet
15–20		GC	Yellowish brown coarse sand. Moderately graded, angular, granitic, 30% fines, wet, loose
20–25		GC	Dark gray coarse gravel. Well graded, angular, andesitic, 90% gravel, 10% medium to coarse sand, loose, wet
25–30		GW	Dark gray coarse gravel. Well graded, angular, andesitic, 80% gravel, 20% med to coarse sand, loose, wet
30–		GW	Yellowish brown coarse to fine gravel. 90% gravel, 10% coarse sand, granitic and andesitic, loose, wet

Northing (Y): 2202914.142 Logged By: Dave van Brocklin
Easting (X): 7063623.726
Coordinate System: NAD83 CA State Plane Zone 2 (feet)
Ref. Point Elevation, ft amsl: 6191.77
Location:

Drilling Dates: 12/10/2008 to 12/11/2008
Drilling Contractor: WDC Exploration & Wells
Drilling Method: Air Rotary
Total Drilled Depth, ft: 135

Fill Materials

0	74	Neat Cement
74	79	Bentonite
79	108	Cemex #3
108	110	Bentonite

Depth, ft	Hole Diam., in.	Casing Diam., in.	Casing Material
-3 - 85	6	2	Sch. 40 PVC Blank
85 - 105	6	2	Sch. 40 PVC 0.02" Screen
105 -105.5	6	2	PVC End Cap

AQUIFER-STREAM INTERACTION

Squaw Valley Public Service District

Poulsen-Deep

Depth (feet)	Lithology	USCS Symbol	Lithologic Description	Spon Pot. 16.00 36.00 56.00 76.00	Comments	Well Construction
35		SW	Yellowish brown coarse to fine gravel. 70% gravel, 30% coarse sand, granitic and andesitic, , loose, wet			
40		SW	Light brown sand. Angular, 5% gravel, 80% coarse sand, 15% fine to medium sand, mostly granitic, loose, wet			
45		SW	Yellowish brown sand. Angular, 50% coarse, 30 % medium, 20% fine, loose, wet			
50		SW	Gray sand with gravel. Well graded, 60% coarse to fine sand, 40% gravel, loose, wet			
55		SW	Yellowish brown sand. Well graded, 60% medium, 20% coarse, 20% fine, small amount of gravel, loose, wet			
60		SW	Yellowish brown sand. Well graded, angular, granitic, 50% fine, 40% med, 10% coarse, loose, wet			
65		GW	Yellowish brown gravel. Well graded, angular, 70% fine gravel, 30% coarse sand, loose, wet			
70						

Northing (Y): 2202914.142 Logged By: Dave van Brocklin
Easting (X): 7063623.726
Coordinate System: NAD83 CA State Plane Zone 2 (feet)
Ref. Point Elevation, ft amsl: 6191.77
Location:

Drilling Dates: 12/10/2008 to 12/11/2008
Drilling Contractor: WDC Exploration & Wells
Drilling Method: Air Rotary
Total Drilled Depth, ft: 135

Fill Materials

Depth, ft	Fill Materials
0 - 74	Neat Cement
74 - 79	Bentonite
79 - 108	Cemex #3
108 - 110	Bentonite

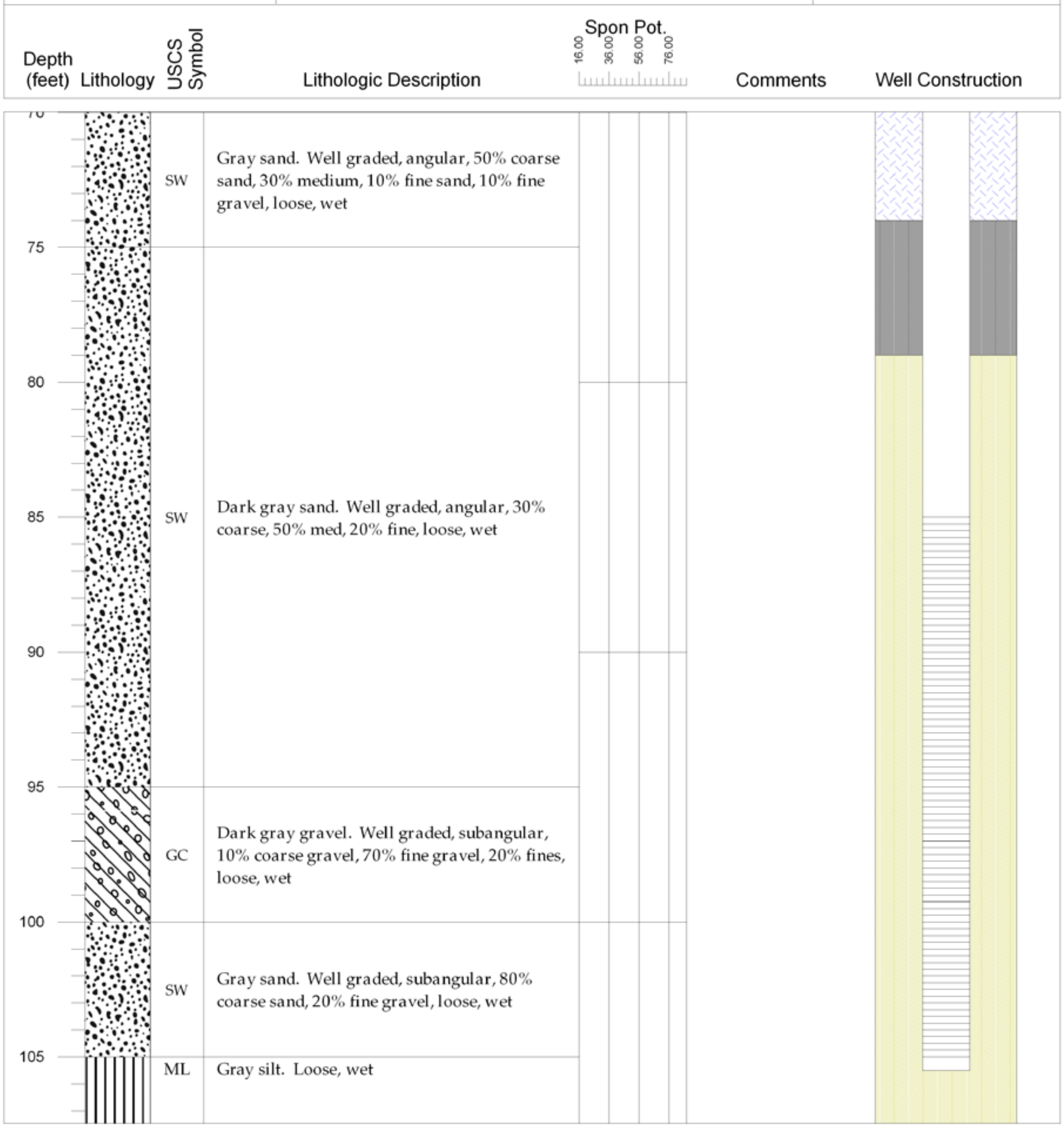
Depth, ft	Hole Diam., in.	Casing Diam., in.	Casing Material
-3 - 85	6	2	Sch. 40 PVC Blank
85 - 105	6	2	Sch. 40 PVC 0.02" Screen
105 -105.5	6	2	PVC End Cap

HydroMetrics WRI

AQUIFER-STREAM INTERACTION

Squaw Valley Public Service District

Poulsen-Deep



Depth (feet)	USCS Symbol	Lithologic Description	Comments
70–75	SW	Gray sand. Well graded, angular, 50% coarse sand, 30% medium, 10% fine sand, 10% fine gravel, loose, wet	
75–95	SW	Dark gray sand. Well graded, angular, 30% coarse, 50% med, 20% fine, loose, wet	
95–100	GC	Dark gray gravel. Well graded, subangular, 10% coarse gravel, 70% fine gravel, 20% fines, loose, wet	
100–105	SW	Gray sand. Well graded, subangular, 80% coarse sand, 20% fine gravel, loose, wet	
105–	ML	Gray silt. Loose, wet	

Northing (Y): 2202914.142 Logged By: Dave van Brocklin
Easting (X): 7063623.726
Coordinate System: NAD83 CA State Plane Zone 2 (feet)
Ref. Point Elevation, ft amsl: 6191.77
Location:

Drilling Dates: 12/10/2008 to 12/11/2008
Drilling Contractor: WDC Exploration & Wells
Drilling Method: Air Rotary
Total Drilled Depth, ft: 135

Fill Materials

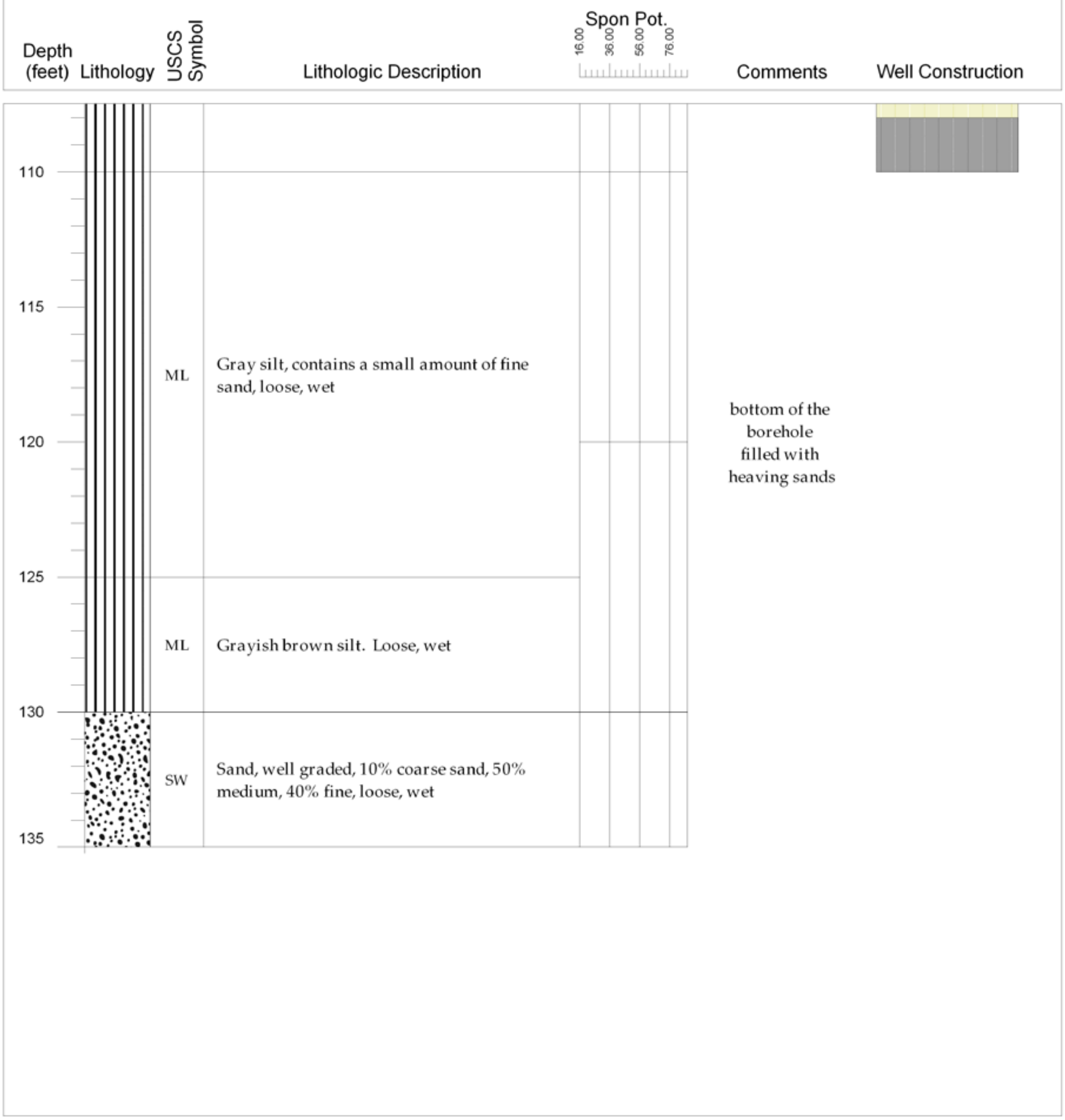
0 - 74	Neat Cement
74 - 79	Bentonite
79 - 108	Cemex #3
108 - 110	Bentonite

Depth, ft	Hole Diam., in.	Casing Diam., in.	Casing Material
-3 - 85	6	2	Sch. 40 PVC Blank
85 - 105	6	2	Sch. 40 PVC 0.02" Screen
105 -105.5	6	2	PVC End Cap

AQUIFER-STREAM INTERACTION

Squaw Valley Public Service District

Poulsen-Deep



ML — Gray silt, contains a small amount of fine sand, loose, wet

ML — Grayish brown silt. Loose, wet

SW — Sand, well graded, 10% coarse sand, 50% medium, 40% fine, loose, wet

bottom of the borehole filled with heaving sands

Northing (Y): 2202914.142 Logged By: Dave van Brocklin
Easting (X): 7063623.726
Coordinate System: NAD83 CA State Plane Zone 2 (feet)
Ref. Point Elevation, ft amsl: 6191.77
Location:

Drilling Dates: 12/10/2008 to 12/11/2008
Drilling Contractor: WDC Exploration & Wells
Drilling Method: Air Rotary
Total Drilled Depth, ft: 135

Fill Materials	
0 - 74	Neat Cement
74 - 79	Bentonite
79 - 108	Cemex #3
108 - 110	Bentonite

Depth, ft	Hole Diam., in.	Casing Diam., in.	Casing Material
-3 - 85	6	2	Sch. 40 PVC Blank
85 - 105	6	2	Sch. 40 PVC 0.02" Screen
105 -105.5	6	2	PVC End Cap

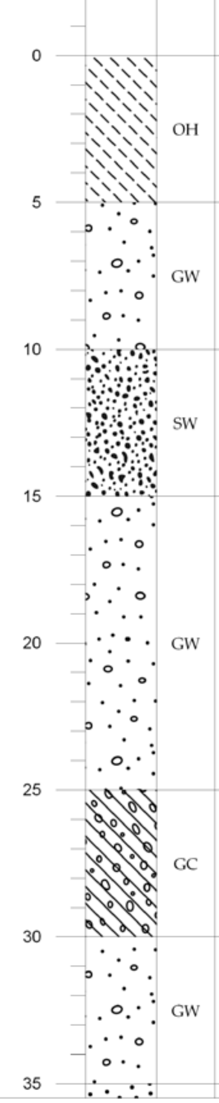
AQUIFER-STREAM INTERACTION

Squaw Valley Public Service District

Page 1 of 2

PlumpJack-Shallow

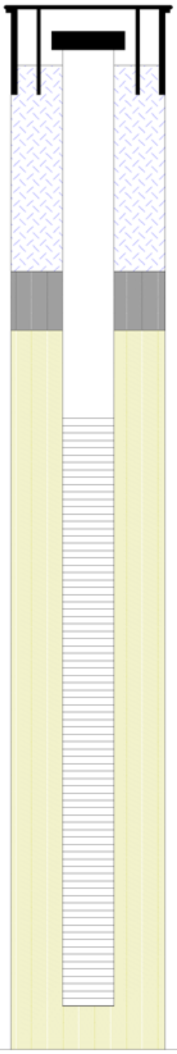
Spon Pot.: 16.00 36.00 56.00 76.00



Depth (feet)	USCS Symbol	Lithologic Description
0 - 5	OH	Dark brown organic clay. Soft, moist
5 - 10	GW	Yellowish brown, well graded gravel with sand, 80% gravel, 20% fine to coarse sand, loose, moist
10 - 15	SW	Yellowish brown sand. Well graded, 40% gravel, 60% sand, loose, moist
15 - 25	GW	Yellowish brown gravel. Well graded, 70% gravel, gravel is largely dark and andesitic, 30% sand, loose, moist
25 - 30	GC	Gravel, well graded with sand and clay, 50% gravel, 25% sand, 25% clay, clay is yellowish brown, gravel is dark gray, loose moist
30 - 35	GW	Yellowish brown, well graded gravel with sand. 80% gravel, 20% fine to coarse sand, loose, moist

Comments: flush surface completion

Well Construction



Northing (Y): 2202758.283 Logged By: Dave van Brocklin
Easting (X): 7061130.612
Coordinate System: NAD83 CA State Plane Zone 2 (feet)
Ref. Point Elevation, ft amsl: 6210.73
Location: PlumpJack Parking Lot

Drilling Dates: 12/17/2008 to 12/18/2008
Drilling Contractor: WDC Exploration & Wells
Drilling Method: Air Rotary
Total Drilled Depth, ft: 39

Depth, ft	Fill Materials
0 - 9	Neat Cement
9 - 11	Bentonite
11 - 39	Cemex #3

Depth, ft	Hole Diam., in.	Casing Diam., in.	Casing Material
-1 - 14	6	2	Sch. 40 PVC Blank
14 - 34	6	2	Sch. 40 PVC 0.02" Screen

Depth (feet)	Lithology	USCS Symbol	Lithologic Description	Spon Pot. 16.00 36.00 56.00 76.00	Comments	Well Construction
40		SP	Yellowish brown sand with gravel. Medium sand with coarse to fine gravel, 85% sand, 15% gravel, loose, moist			

Northing (Y): 2202758.283 Logged By: Dave van Brocklin
Easting (X): 7061130.612
Coordinate System: NAD83 CA State Plane Zone 2 (feet)
Ref. Point Elevation, ft amsl: 6210.73
Location: PlumpJack Parking Lot

Drilling Dates: 12/17/2008 to 12/18/2008
Drilling Contractor: WDC Exploration & Wells
Drilling Method: Air Rotary
Total Drilled Depth, ft: 39

	Fill Materials
0 - 9	Neat Cement
9 - 11	Bentonite
11 - 39	Cemex #3

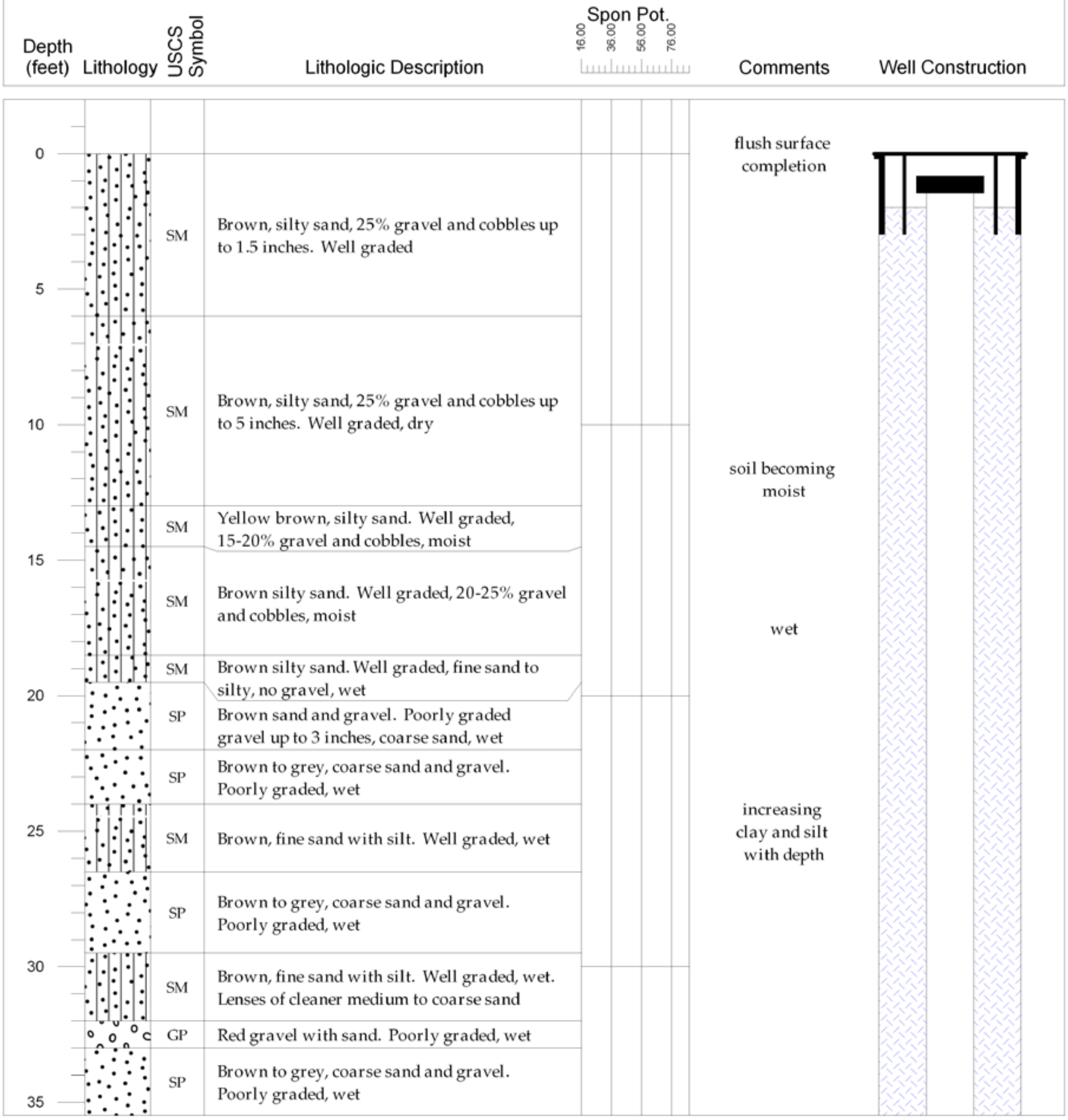
Depth, ft	Hole Diam., in.	Casing Diam., in.	Casing Material
-1 - 14	6	2	Sch. 40 PVC Blank
14 - 34	6	2	Sch. 40 PVC 0.02" Screen

HydroMetrics WRI

AQUIFER-STREAM INTERACTION

Squaw Valley Public Service District

PlumpJack-Deep



USCS Symbol	Lithologic Description
SM	Brown, silty sand, 25% gravel and cobbles up to 1.5 inches. Well graded
SM	Brown, silty sand, 25% gravel and cobbles up to 5 inches. Well graded, dry
SM	Yellow brown, silty sand. Well graded, 15-20% gravel and cobbles, moist
SM	Brown silty sand. Well graded, 20-25% gravel and cobbles, moist
SM	Brown silty sand. Well graded, fine sand to silty, no gravel, wet
SP	Brown sand and gravel. Poorly graded gravel up to 3 inches, coarse sand, wet
SP	Brown to grey, coarse sand and gravel. Poorly graded, wet
SM	Brown, fine sand with silt. Well graded, wet
SP	Brown to grey, coarse sand and gravel. Poorly graded, wet
SM	Brown, fine sand with silt. Well graded, wet. Lenses of cleaner medium to coarse sand
GP	Red gravel with sand. Poorly graded, wet
SP	Brown to grey, coarse sand and gravel. Poorly graded, wet

Comments:

flush surface completion

soil becoming moist

wet

increasing clay and silt with depth

Northing (Y): 2202750.109 Logged By: Derrik Williams
Easting (X): 7061183.898
Coordinate System: NAD83 CA State Plane Zone 2 (feet)
Ref. Point Elevation, ft amsl: 6209.6
Location: PlumpJack Parking Lot

Drilling Dates: 6/1/2010
Drilling Contractor: Boart Longyear
Drilling Method: Sonic
Total Drilled Depth, ft: 133

Fill Materials

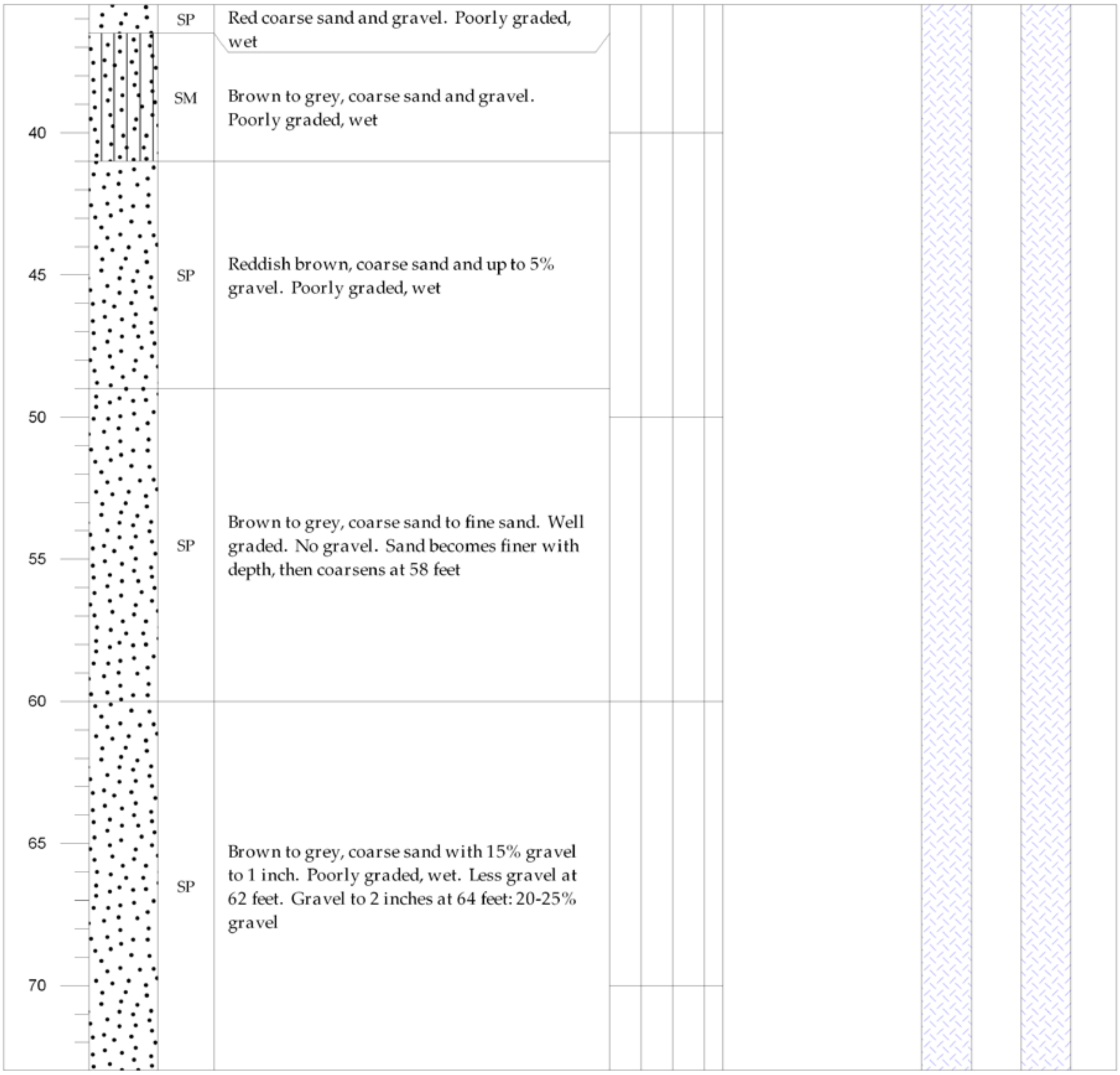
Depth, ft	Fill Materials
0 - 92	Neat Cement + 5% Bentonite
92 - 97	Bentonite
97 - 133	Gravel pack: Lonestar #3

Depth, ft	Hole Diam., in.	Casing Diam., in.	Casing Material
-1 - 102	6	2	Sch. 40 PVC Blank
102 - 132	6	2	Sch. 40 PVC 0.02" Screen

AQUIFER-STREAM INTERACTION

Squaw Valley Public Service District

PlumpJack-Deep



USCS Symbol	Lithologic Description
SP	Red coarse sand and gravel. Poorly graded, wet
SM	Brown to grey, coarse sand and gravel. Poorly graded, wet
SP	Reddish brown, coarse sand and up to 5% gravel. Poorly graded, wet
SP	Brown to grey, coarse sand to fine sand. Well graded. No gravel. Sand becomes finer with depth, then coarsens at 58 feet
SP	Brown to grey, coarse sand with 15% gravel to 1 inch. Poorly graded, wet. Less gravel at 62 feet. Gravel to 2 inches at 64 feet: 20-25% gravel

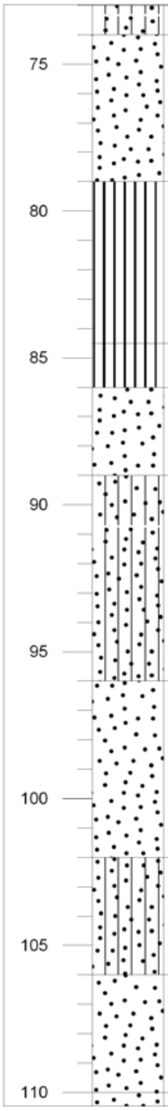
Northing (Y): 2202750.109 Logged By: Derrik Williams
Easting (X): 7061183.898
Coordinate System: NAD83 CA State Plane Zone 2 (feet)
Ref. Point Elevation, ft amsl: 6209.6
Location: PlumpJack Parking Lot

Drilling Dates: 6/1/2010
Drilling Contractor: Boart Longyear
Drilling Method: Sonic
Total Drilled Depth, ft: 133

Fill Materials	
0 - 92	Neat Cement + 5% Bentonite
92 - 97	Bentonite
97 - 133	Gravel pack: Lonestar #3

Depth, ft	Hole Diam., in.	Casing Diam., in.	Casing Material
-1 - 102	6	2	Sch. 40 PVC Blank
102 - 132	6	2	Sch. 40 PVC 0.02" Screen

Depth (feet) | Lithology | USCS Symbol | Lithologic Description | Spon Pot. | Comments | Well Construction



USCS Symbol	Lithologic Description
SM	Brown silty sand. Fine sand, well graded, wet
SP	Brown to grey, coarse to fine sand. Moderately graded, wet
ML	Brown silt. Stiff, horizontal bedding, wet
ML	Brown silt with 20-25% sand and gravel to 3 inch diameter. Stiff, no clear bedding
SP	Brown, medium to coarse sand. Poorly graded, moisit. 3% gravel to 0.5 inch diameter
SM	Brown, medium sand with significant silt. 20% gravel to 2 inches. Medium stiff, well graded, no structure. Color change to grey at 92 feet, color change to brown at 93 feet
SP	Brown, medium sand with 5% gravel to 0.5 inches. Poorly graded, moist. Increasing silt with depth
SM	Grey, silty sand. Fine sand with 5% gravel up to 1 inch. Medium stiff, moist. Color change to brown at 103 feet. Lenses of medium sand.
SP	Brown to grey, coarse sand with 10% gravel to 2 inches. Poorly graded, wet

Northing (Y): 2202750.109 Logged By: Derrik Williams
Easting (X): 7061183.898
Coordinate System: NAD83 CA State Plane Zone 2 (feet)
Ref. Point Elevation, ft amsl: 6209.6
Location: PlumpJack Parking Lot

Drilling Dates: 6/1/2010
Drilling Contractor: Boart Longyear
Drilling Method: Sonic
Total Drilled Depth, ft: 133

Fill Materials

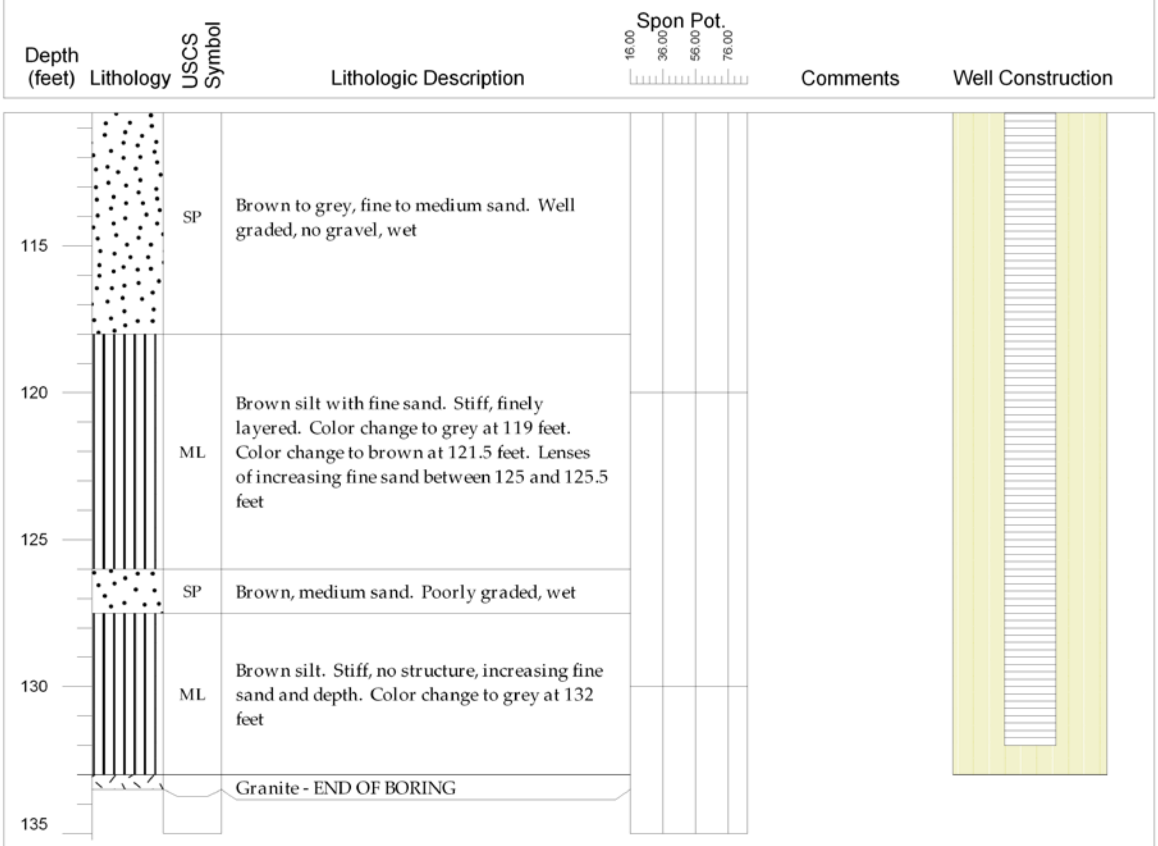
Depth	Fill Materials
0 - 92	Neat Cement + 5% Bentonite
92 - 97	Bentonite
97 - 133	Gravel pack: Lonestar #3

Depth, ft	Hole Diam., in.	Casing Diam., in.	Casing Material
-1 - 102	6	2	Sch. 40 PVC Blank
102 - 132	6	2	Sch. 40 PVC 0.02" Screen

AQUIFER-STREAM INTERACTION

Squaw Valley Public Service District

PlumpJack-Deep



USCS Symbol	Lithologic Description
SP	Brown to grey, fine to medium sand. Well graded, no gravel, wet
ML	Brown silt with fine sand. Stiff, finely layered. Color change to grey at 119 feet. Color change to brown at 121.5 feet. Lenses of increasing fine sand between 125 and 125.5 feet
SP	Brown, medium sand. Poorly graded, wet
ML	Brown silt. Stiff, no structure, increasing fine sand and depth. Color change to grey at 132 feet
	Granite - END OF BORING

Northing (Y): 2202750.109 Logged By: Derrik Williams
Easting (X): 7061183.898
Coordinate System: NAD83 CA State Plane Zone 2 (feet)
Ref. Point Elevation, ft amsl: 6209.6
Location: PlumpJack Parking Lot

Drilling Dates: 6/1/2010
Drilling Contractor: Boart Longyear
Drilling Method: Sonic
Total Drilled Depth, ft: 133

Depth, ft	Fill Materials
0 - 92	Neat Cement + 5% Bentonite
92 - 97	Bentonite
97 - 133	Gravel pack: Lonestar #3

Depth, ft	Hole Diam., in.	Casing Diam., in.	Casing Material
-1 - 102	6	2	Sch. 40 PVC Blank
102 - 132	6	2	Sch. 40 PVC 0.02" Screen

APPENDIX D: Well Installation Photos

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Drilling, December 2008

Rig Setup

Drilling Shallow PlumpJack Squaw Valley Inn Well

Completed PlumpJack Squaw Valley Inn Well

Completed Poulsen Property Wells
Drilling, June 2010

Rig Setup

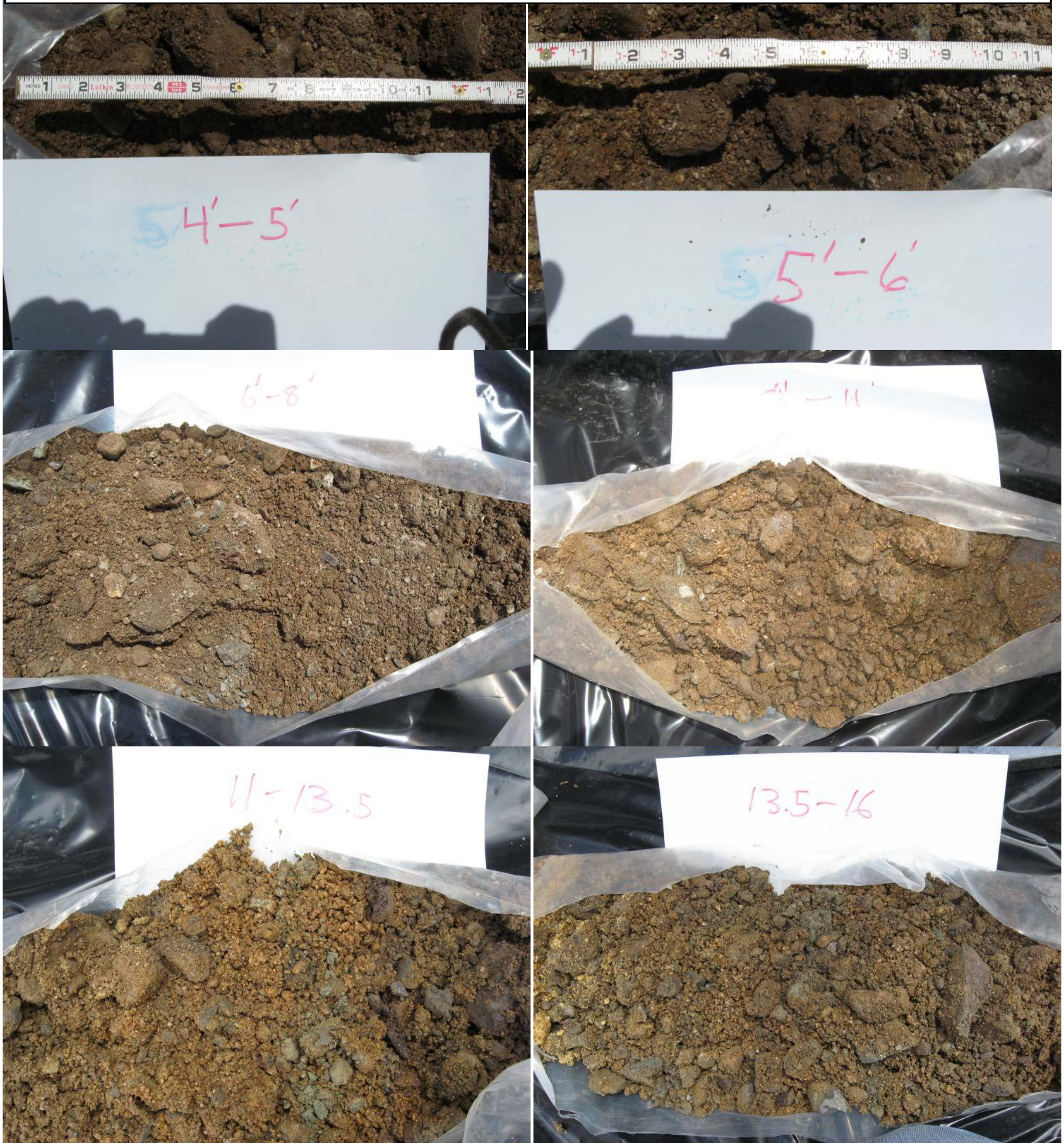
Drilling

Grouting

Setting Protective Casing

Completed PlumpJack Squaw Valley Inn Deep Well

Well Cuttings from PlumpJack Squaw Valley Inn Deep Well

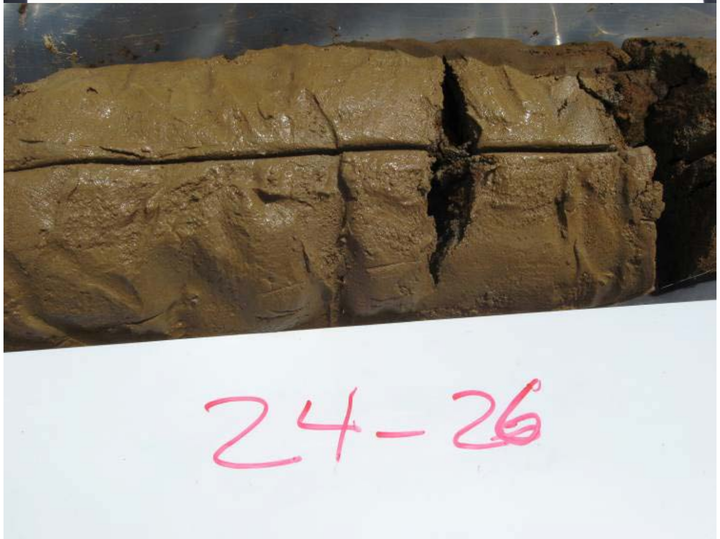



16-18


18-20


20-22


22-24


24-26


26-28


28-30


30-32


32-34


34-36


36-38.5


38.5-41


41-43.5


43.5-46


46-48.5


48.5-51


51-53.5


53.5-56


56- 58.5


58.5-61


61- 63.5


63.5-66


66-68.5


68,5-71


71- 73.5


73.5-76


76-78.5


78.5-81

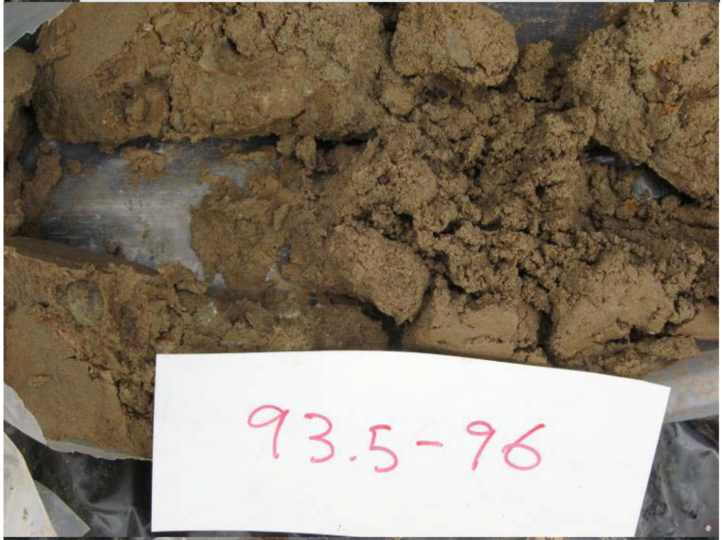

81- 84


84- 86


86-88.5


88.5-91


91-93.5


93.5-96


96-98.5


98.5-101


101-103.5


103.5-106


106-108.5


108.5-111


111-113.5

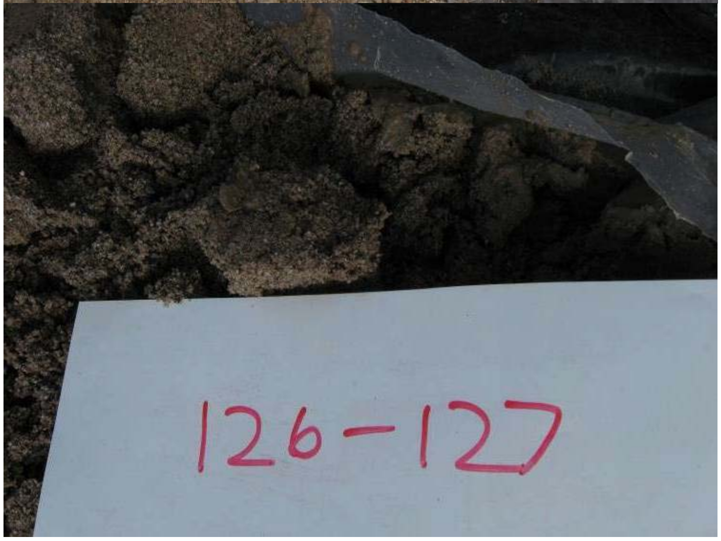

113.5-116


116 - 118.5


118.5 - 121


121- 123.5

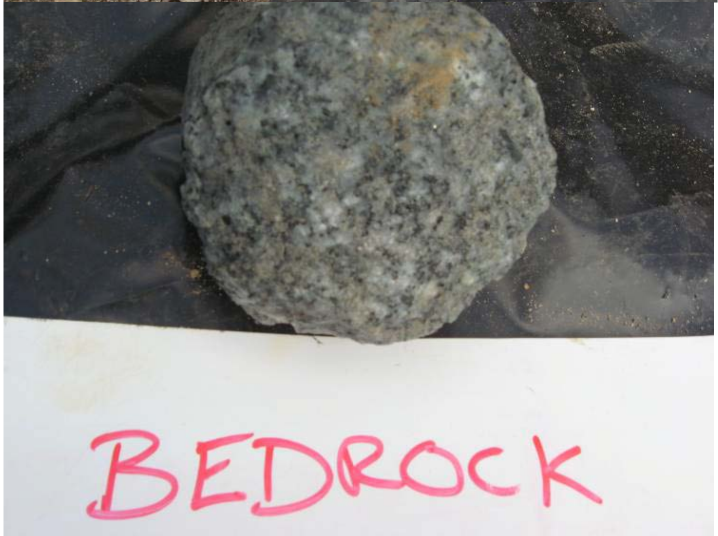

123.5- 126


126-127


127- 129


129- 131


131 - 133


BEDROCK

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APPENDIX E: Temperature Probe and Transducer Photographs

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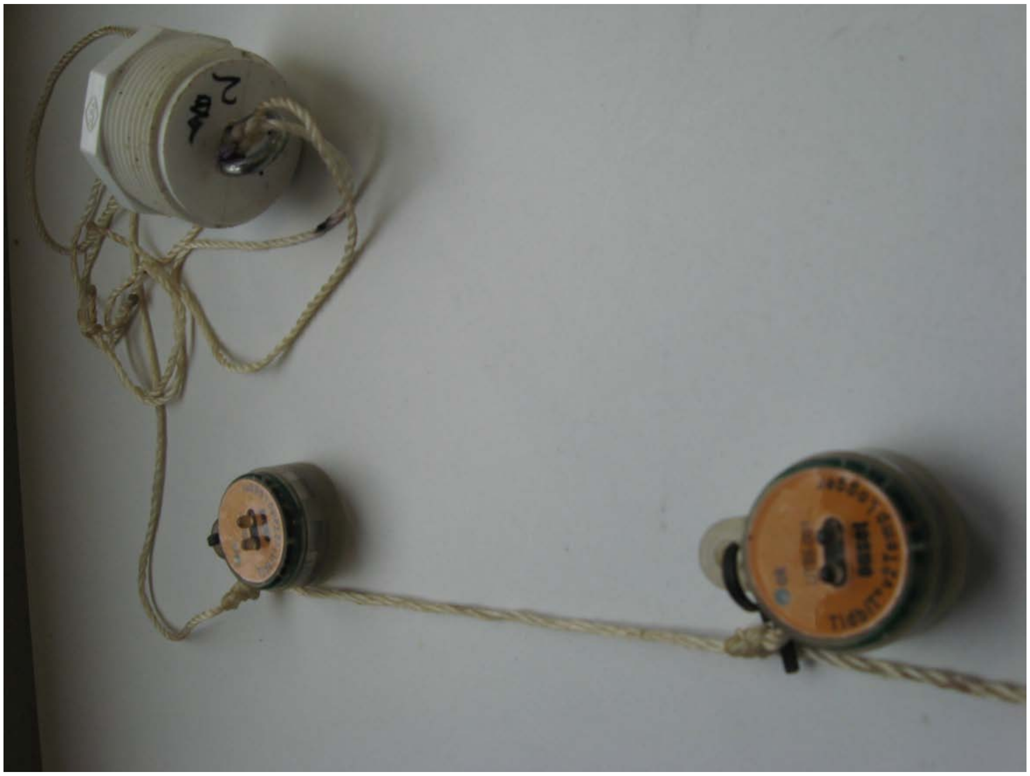
Installing Temperature Probes

Installing Temperature Probes

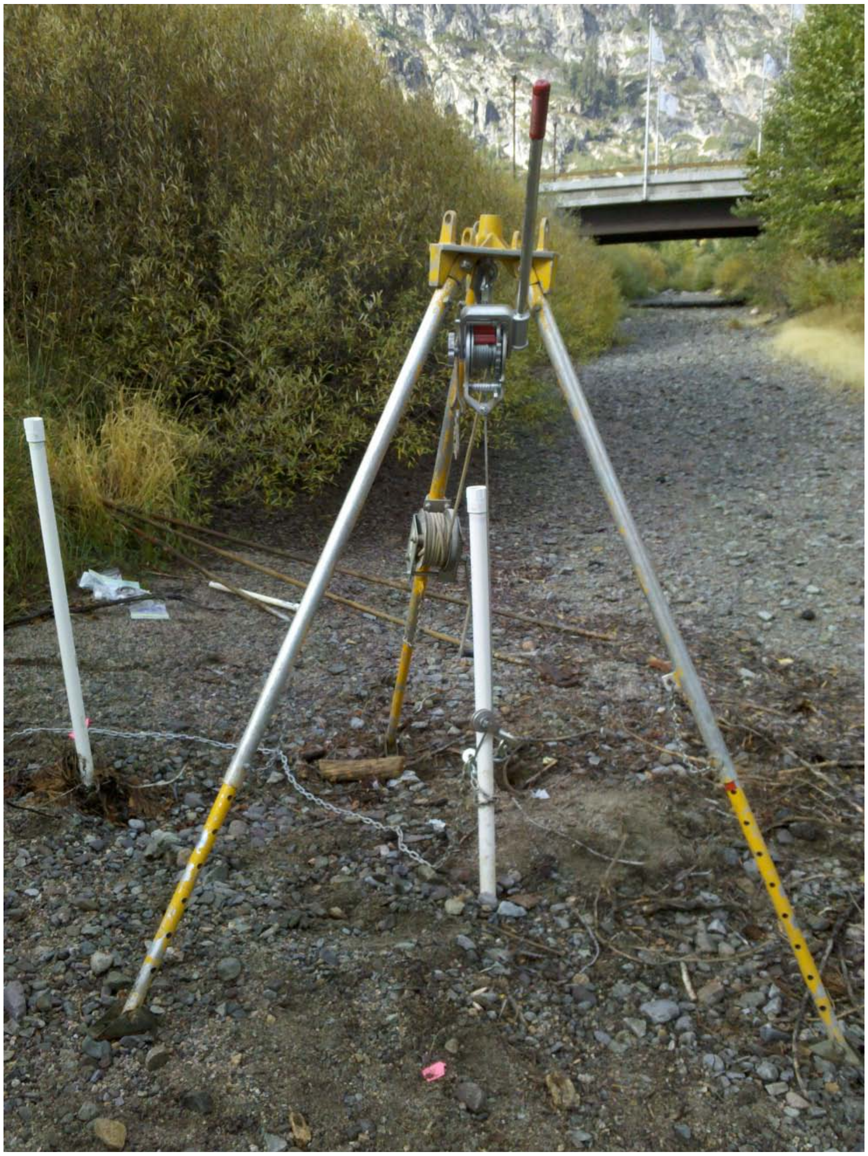
Eastern Set of Temperatuere Probes

Western Set of Temperature Probes



Example Temperature Data Loggers

Example Piezometer Data Loggers



Removing Temperature Probes and Piezometers

Restored Creekbed at Eastern Set of Temperature Probes

Restored Creekbed at Western Set of Temperature Probes

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APPENDIX F: Survey Data

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GeoTracker XY

NAD83 - California State Plane Coordinates Zone 2 - US Survey Feet
NGVD29 - Based on BM H-172 (PID KS0274) EL: 6177.99

GLOBAL_ID	FIELD_PT_NAME	FIELD_PT_CLASS	XY_SURVEY_DATE	LATITUDE	LONGTITUDE	NORTHING	EASTING	ELEVATION	XY_METHOD	XY_DATUM	XY_ACC_VAL	XY_SURVEY_ORG	GPS_EQUIP_TYPE
??	601	MW	10/1/2010	39.1979586	-120.2300327	2202983.734	7063225.154	6197.74	STAT	NAD83	±0.3cm	Andregg Geomatics	T40S
??	602	MW	10/1/2010	39.1979623	-120.2300576	2202985.038	7063218.054	6197.63	STAT	NAD83	±0.3cm	Andregg Geomatics	T40S
??	603	MW	10/1/2010	39.1980844	-120.2300289	2203029.557	7063225.318	6187.75	STAT	NAD83	±0.3cm	Andregg Geomatics	T40S
??	604	MW	10/1/2010	39.1980844	-120.2300294	2203029.545	7063225.202	6187.72	STAT	NAD83	±0.3cm	Andregg Geomatics	T40S
??	605	MW	10/1/2010	39.1977463	-120.2286313	2202914.142	7063623.726	6191.77	STAT	NAD83	±0.3cm	Andregg Geomatics	T40S
??	606	MW	10/1/2010	39.1977468	-120.2286313	2202914.327	7063623.730	6192.04	STAT	NAD83	±0.3cm	Andregg Geomatics	T40S
??	607	MW	10/1/2010	39.1977616	-120.2286477	2202919.646	7063618.962	6192.31	STAT	NAD83	±0.3cm	Andregg Geomatics	T40S
??	608	MW	10/1/2010	39.1977622	-120.2286476	2202919.834	7063618.986	6192.50	STAT	NAD83	±0.3cm	Andregg Geomatics	T40S
??	609	MW	10/1/2010	39.1978166	-120.2319902	2202921.204	7062671.521	6204.90	STAT	NAD83	±0.3cm	Andregg Geomatics	T40S
??	610	MW	10/1/2010	39.1984107	-120.2320092	2203137.427	7062661.918	6188.46	STAT	NAD83	±0.3cm	Andregg Geomatics	T40S
??	611	MW	10/1/2010	39.1984107	-120.2320095	2203137.436	7062661.833	6188.53	STAT	NAD83	±0.3cm	Andregg Geomatics	T40S
??	612	MW	10/1/2010	39.1984103	-120.2319939	2203137.364	7062666.277	6188.59	STAT	NAD83	±0.3cm	Andregg Geomatics	T40S
??	613	MW	10/1/2010	39.1983864	-120.2320039	2203128.635	7062663.611	6188.55	STAT	NAD83	±0.3cm	Andregg Geomatics	T40S
??	614	MW	10/1/2010	39.1974515	-120.2374377	2202758.283	7061130.612	6210.73	STAT	NAD83	±0.3cm	Andregg Geomatics	T40S
??	615	MW	10/1/2010	39.1974519	-120.2374382	2202758.431	7061130.471	6211.05	STAT	NAD83	±0.3cm	Andregg Geomatics	T40S
??	616	MW	10/1/2010	39.1974262	-120.2372503	2202750.109	7061183.898	6209.60	STAT	NAD83	±0.3cm	Andregg Geomatics	T40S
??	617	MW	10/1/2010	39.1974255	-120.2372507	2202749.821	7061183.780	6209.36	STAT	NAD83	±0.3cm	Andregg Geomatics	T40S
??	618	MW	10/1/2010	39.1979593	-120.2300325	2202983.987	7063225.197	6198.25	STAT	NAD83	±0.3cm	Andregg Geomatics	T40S
??	619	MW	10/1/2010	39.1979633	-120.2300574	2202985.296	7063218.128	6198.30	STAT	NAD83	±0.3cm	Andregg Geomatics	T40S

FIELD_PT_NAME	SITE_NAME
601	MW 5 Deep; PVC Pipe
602	MW 5 Shallow; PVC Pipe
603	Stilling Well near 5D/5S; PVC Pipe
604	Deep Piezometer near 5D/5S; Steel Pipe
605	Poulsen Deep; PVC Pipe
606	Poulsen Deep; Steel Casing
607	Poulsen Shallow; PVC Pipe
608	Poulsen Shallow; Steel Casing
609	SCPSD Well 4R; Sounding Tube
610	Stilling Well east of Bridge; PVC Pipe
611	Shallow Piezometer east of Bridge; Steel Pipe
612	Deep Piezometer east of Bridge; Steel Pipe
613	Bank Piezometer east of Bridge; Steel Pipe
614	PlumpJack Shallow; PVC Pipe
615	PlumpJack Shallow; Steel Grate
616	PlumpJack Deep; Steel Grate
617	PlumpJack Deep; PVC Pipe
618	MW 5 Deep; Steel Grate
619	MW 5 Shallow; Steel Grate

GeoTracker Z

NAD83 - California State Plane Coordinates Zone 2 - US Survey Feet

NGVD29 Based on BM H-172 (PID KS0274) EL: 6177.99

GLOBAL_ID	FIELD_PT_NAME	ELEV_SURVEY_DATE	ELEVATION	ELEV_METHOD	ELEV_DATUM	ELEV_ACC_VAL
??	601	10/1/2010	6197.74	DIG	NGVD29	±0.6 cm
??	602	10/1/2010	6197.63	DIG	NGVD29	±0.6 cm
??	603	10/1/2010	6187.75	DIG	NGVD29	±0.6 cm
??	604	10/1/2010	6187.72	DIG	NGVD29	±0.6 cm
??	605	10/1/2010	6191.77	DIG	NGVD29	±0.6 cm
??	606	10/1/2010	6192.04	DIG	NGVD29	±0.6 cm
??	607	10/1/2010	6192.31	DIG	NGVD29	±0.6 cm
??	608	10/1/2010	6192.50	DIG	NGVD29	±0.6 cm
??	609	10/1/2010	6204.90	DIG	NGVD29	±0.6 cm
??	610	10/1/2010	6188.46	DIG	NGVD29	±0.6 cm
??	611	10/1/2010	6188.53	DIG	NGVD29	±0.6 cm
??	612	10/1/2010	6188.59	DIG	NGVD29	±0.6 cm
??	613	10/1/2010	6188.55	DIG	NGVD29	±0.6 cm
??	614	10/1/2010	6210.73	DIG	NGVD29	±0.6 cm
??	615	10/1/2010	6211.05	DIG	NGVD29	±0.6 cm
??	616	10/1/2010	6209.60	DIG	NGVD29	±0.6 cm
??	617	10/1/2010	6209.36	DIG	NGVD29	±0.6 cm
??	618	10/1/2010	6198.25	DIG	NGVD29	±0.6 cm
??	619	10/1/2010	6198.30	DIG	NGVD29	±0.6 cm

FIELD_PT_NAME	SITE_NAME
601	MW 5 Deep; PVC Pipe
602	MW 5 Shallow; PVC Pipe
603	Stilling Well near 5D/5S; PVC Pipe
604	Deep Piezometer near 5D/5S; Steel Pipe
605	Poulsen Deep; PVC Pipe
606	Poulsen Deep; Steel Casing
607	Poulsen Shallow; PVC Pipe
608	Poulsen Shallow; Steel Casing
609	SCPSD Well 4R; Sounding Tube
610	Stilling Well east of Bridge; PVC Pipe
611	Shallow Piezometer east of Bridge; Steel Pipe
612	Deep Piezometer east of Bridge; Steel Pipe
613	Bank Piezometer east of Bridge; Steel Pipe
614	PlumpJack Shallow; PVC Pipe
615	PlumpJack Shallow; Steel Grate
616	PlumpJack Deep; Steel Grate
617	PlumpJack Deep; PVC Pipe
618	MW 5 Deep; Steel Grate

GeoTracker Z

NAD83 - California State Plane Coordinates Zone 2 - US Survey Feet
NGVD29 Based on BM H-172 (PID KS0274) EL: 6177.99

619	MW 5 Shallow; Steel Grate

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APPENDIX G: Graphed Aquifer Test Data

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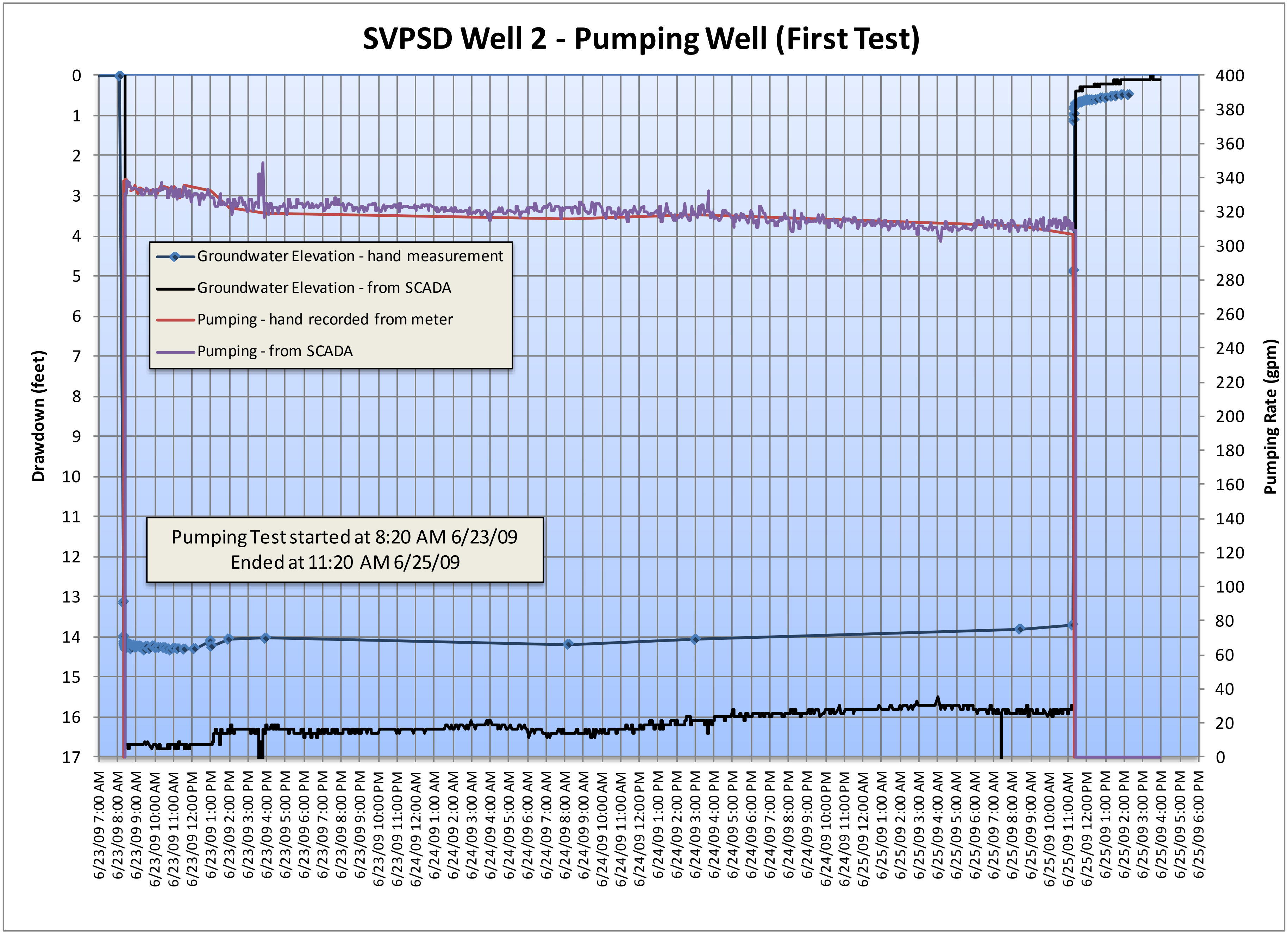
SVPSD Well 2 - Pumping Well (First Test)
Drawdown (feet)
Pumping Rate (gpm)
Groundwater Elevation - hand measurement
Groundwater Elevation - from SCADA
Pumping - hand recorded from meter
Pumping - from SCADA
Pumping Test started at 8:20 AM 6/23/09
Ended at 11:20 AM 6/25/09
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
6/23/09 7:00 AM
6/23/09 8:00 AM
6/23/09 9:00 AM
6/23/09 10:00 AM
6/23/09 11:00 AM
6/23/09 12:00 PM
6/23/09 1:00 PM
6/23/09 2:00 PM
6/23/09 3:00 PM
6/23/09 4:00 PM
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6/24/09 10:00 PM
6/24/09 11:00 PM
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6/25/09 6:00 AM
6/25/09 7:00 AM
6/25/09 8:00 AM
6/25/09 9:00 AM
6/25/09 10:00 AM
6/25/09 11:00 AM
6/25/09 12:00 PM
6/25/09 1:00 PM
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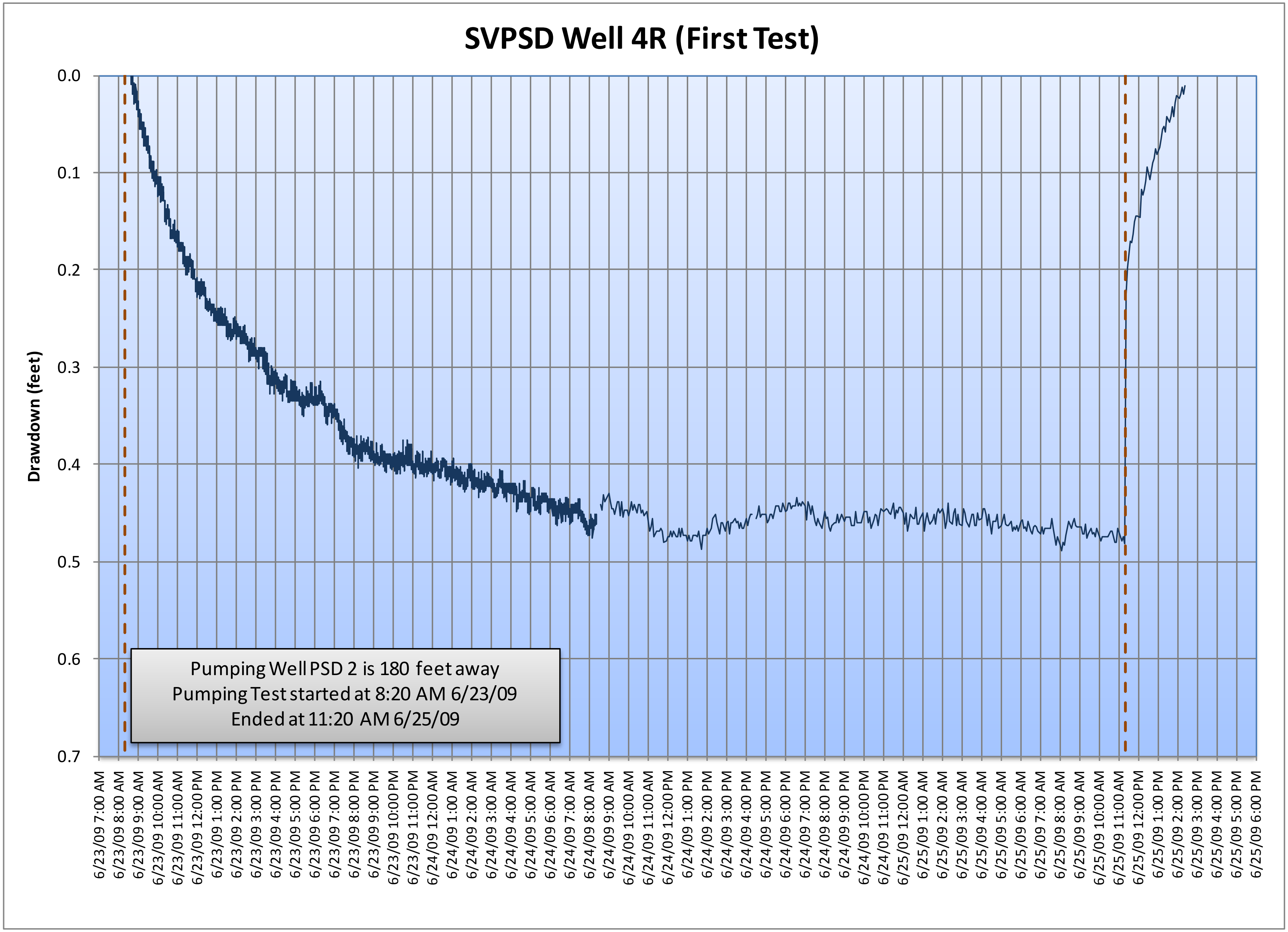
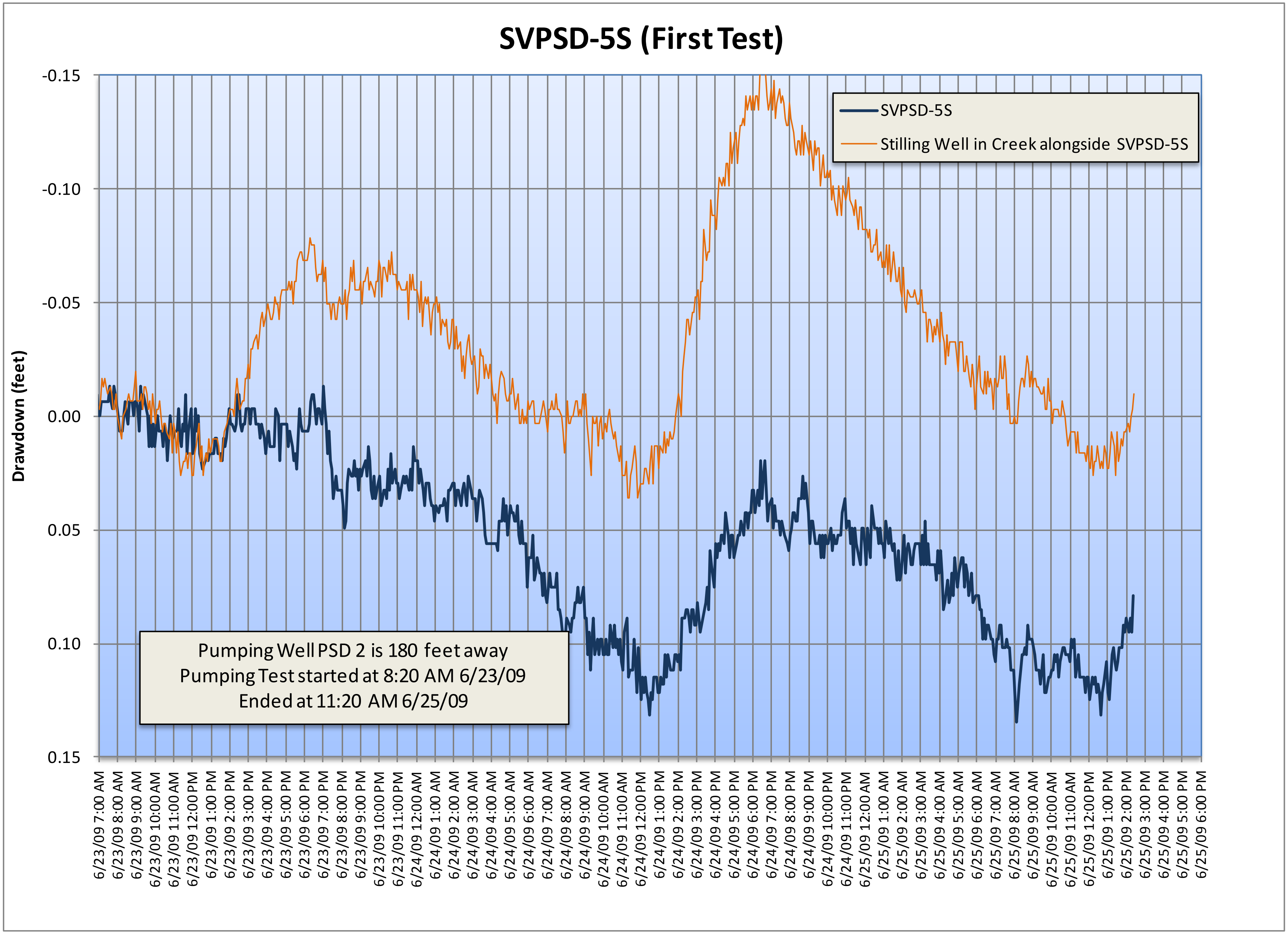
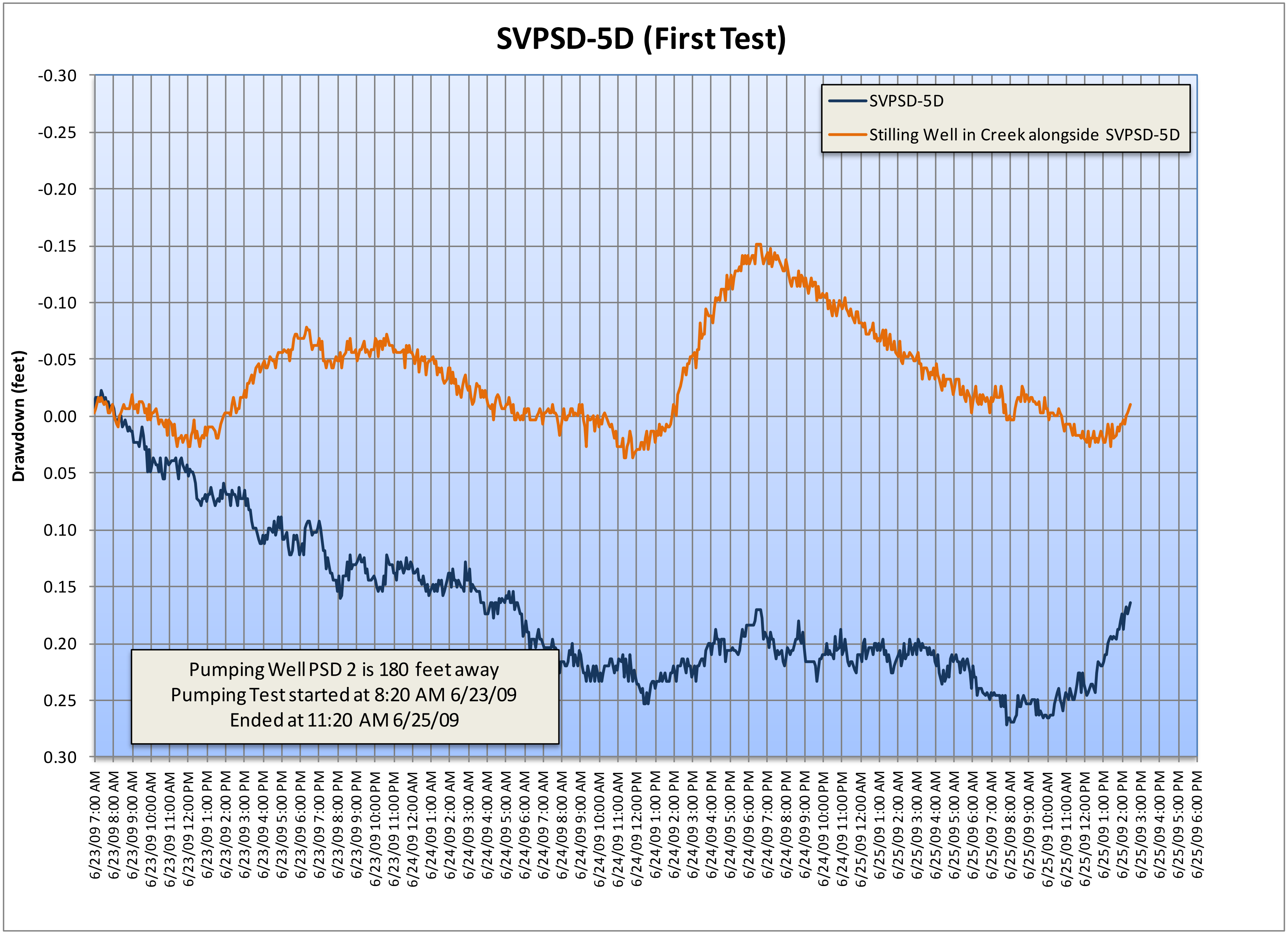
6/25/09 6:00 PM



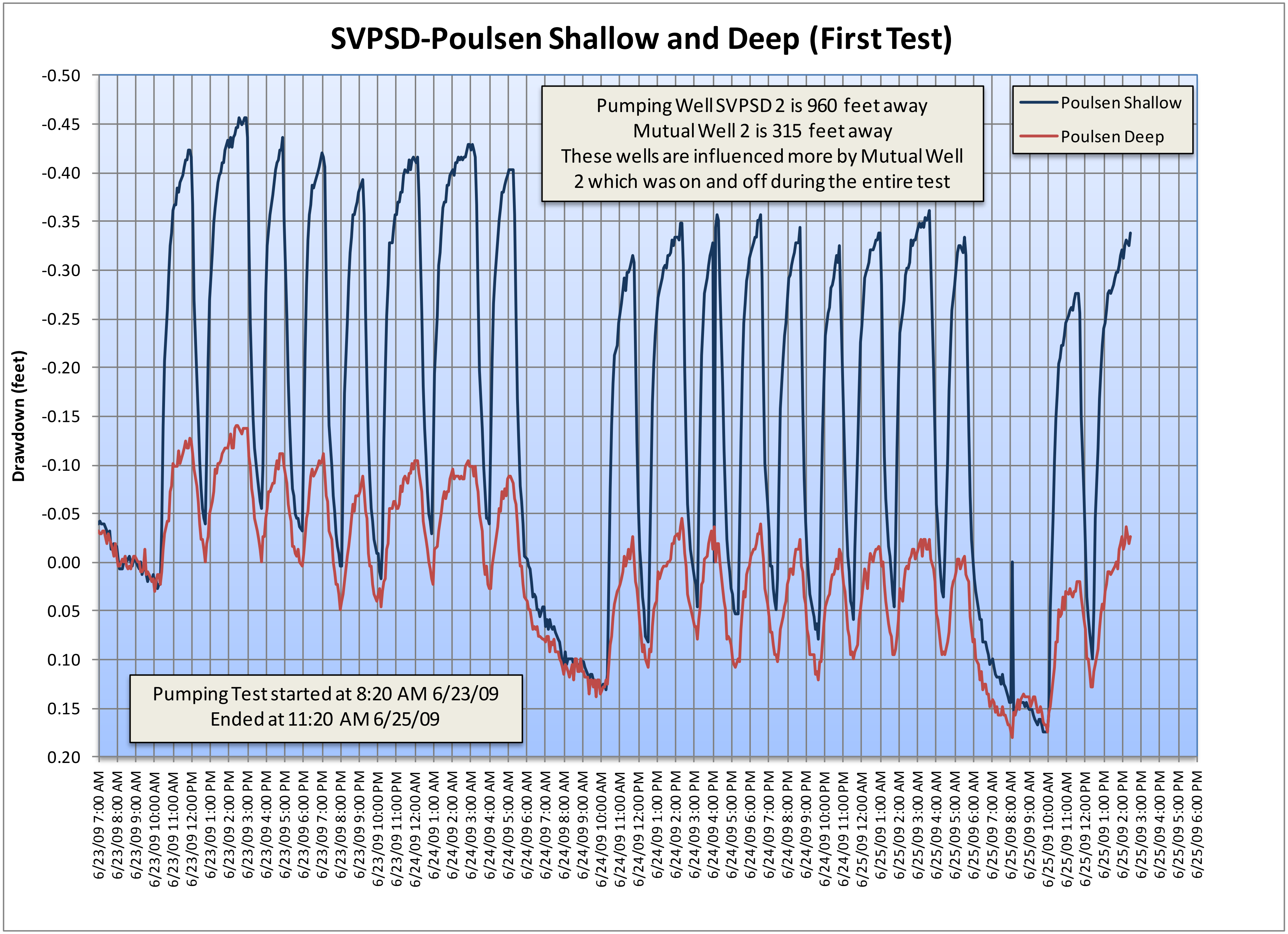
Pumping Well PSD 2 is 180 feet away
Pumping Test started at 8:20 AM 6/23/09
Ended at 11:20 AM 6/25/09



Pumping Well PSD 2 is 180 feet away
Pumping Test started at 8:20 AM 6/23/09
Ended at 11:20 AM 6/25/09

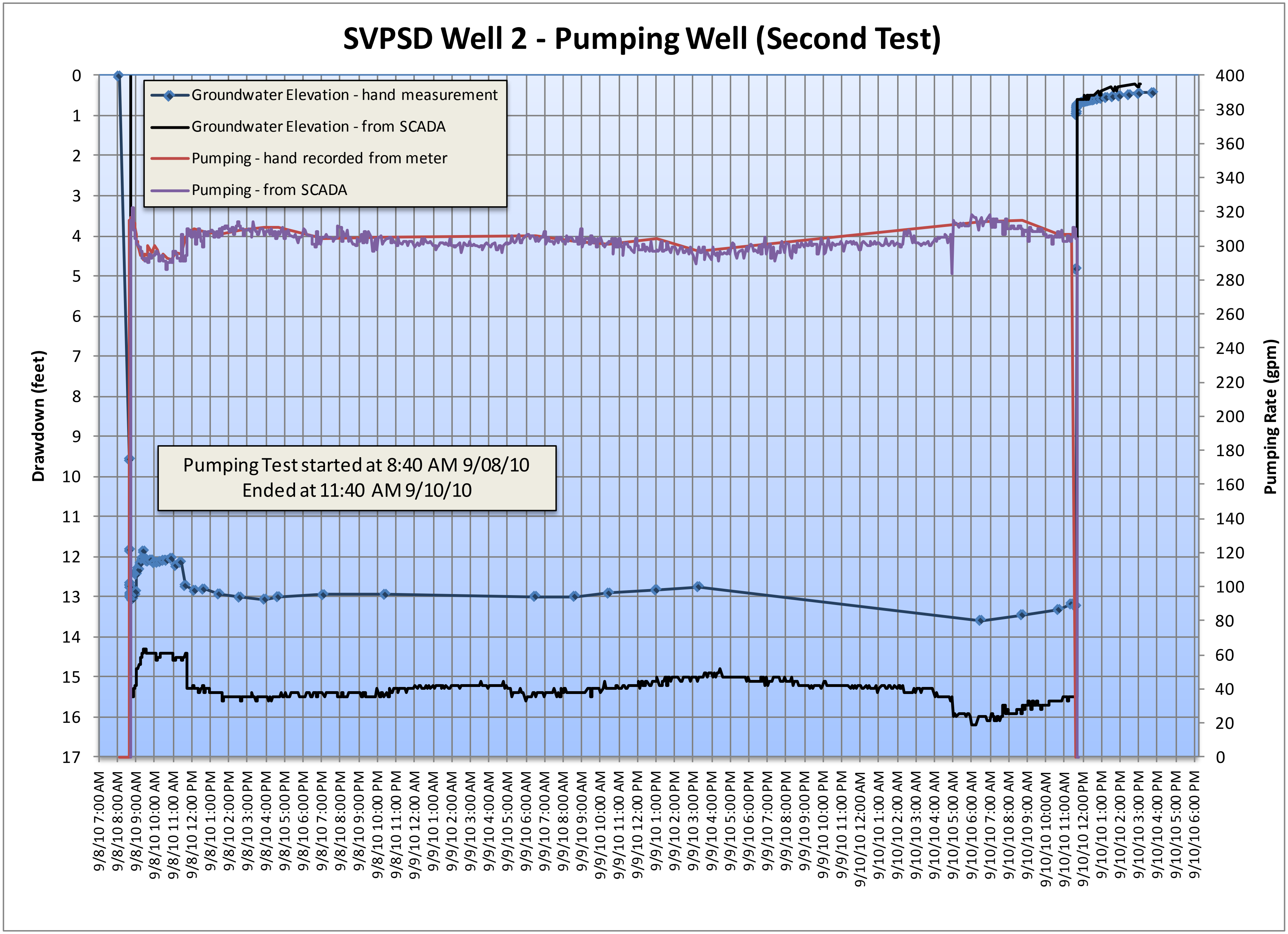


Pumping Well PSD 2 is 180 feet away
Pumping Test started at 8:20 AM 6/23/09
Ended at 11:20 AM 6/25/09

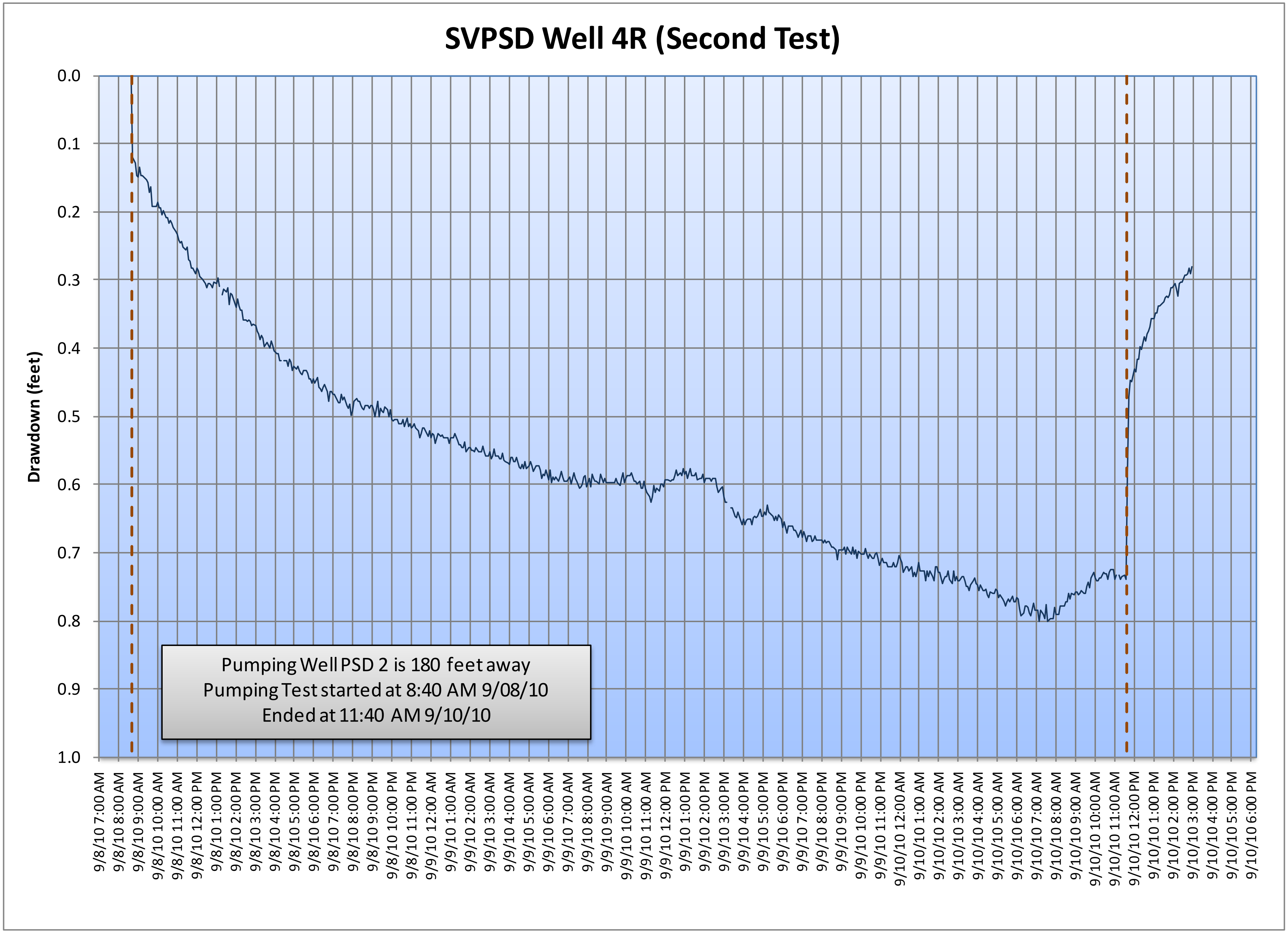


Pumping Well SVPSD 2 is 960 feet away
Mutual Well 2 is 315 feet away
These wells are influenced more by Mutual Well 2 which was on and off during the entire test

Pumping Test started at 8:20 AM 6/23/09
Ended at 11:20 AM 6/25/09



Pumping Test started at 8:40 AM 9/08/10
Ended at 11:40 AM 9/10/10


SVPSD Well 4R (Second Test)
Drawdown (feet)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Pumping Well PSD 2 is 180 feet away
Pumping Test started at 8:40 AM 9/08/10
Ended at 11:40 AM 9/10/10
9/8/10 7:00AM
9/8/10 8:00AM
9/8/10 9:00AM
9/8/10 10:00 AM
9/8/10 11:00 AM
9/8/10 12:00 PM
9/8/10 1:00PM
9/8/10 2:00PM
9/8/10 3:00PM
9/8/10 4:00PM
9/8/10 5:00PM
9/8/10 6:00PM
9/8/10 7:00PM
9/8/10 8:00PM
9/8/10 9:00PM
9/8/10 10:00PM
9/8/10 11:00 PM
9/9/10 12:00 AM
9/9/10 1:00AM
9/9/10 2:00AM
9/9/10 3:00AM
9/9/10 4:00AM
9/9/10 5:00AM
9/9/10 6:00AM
9/9/10 7:00AM
9/9/10 8:00AM
9/9/10 9:00AM
9/9/10 10:00 AM
9/9/10 11:00 AM
9/9/10 12:00 PM
9/9/10 1:00PM
9/9/10 2:00PM
9/9/10 3:00PM
9/9/10 4:00PM
9/9/10 5:00PM
9/9/10 6:00PM
9/9/10 7:00PM
9/9/10 8:00PM
9/9/10 9:00PM
9/9/10 10:00 PM
9/9/10 11:00 PM
9/10/10 12:00AM
9/10/10 1:00 AM
9/10/10 2:00 AM
9/10/10 3:00 AM
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9/10/10 6:00 AM
9/10/10 7:00 AM
9/10/10 8:00 AM
9/10/10 9:00 AM
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9/10/10 11:00 AM
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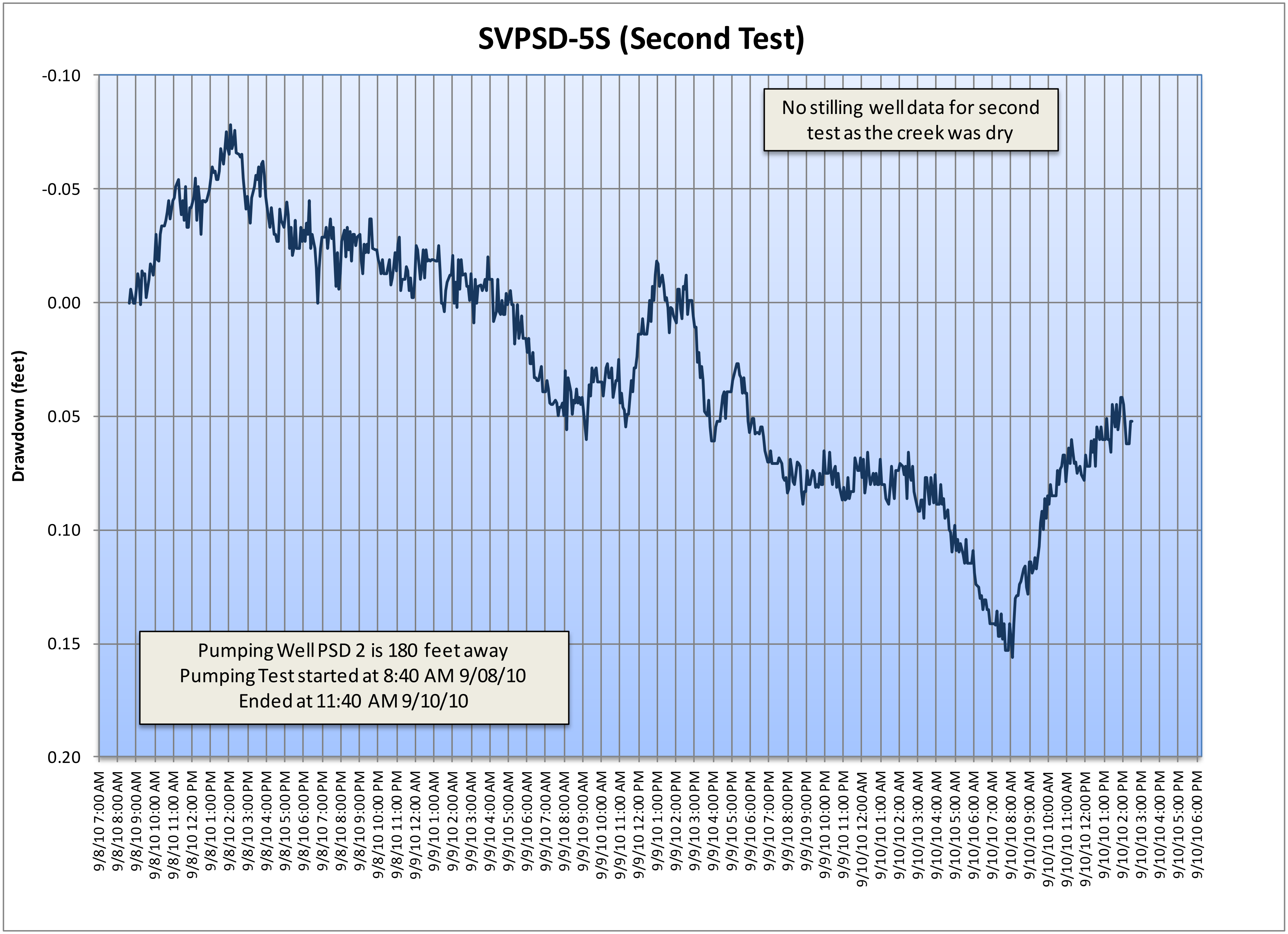
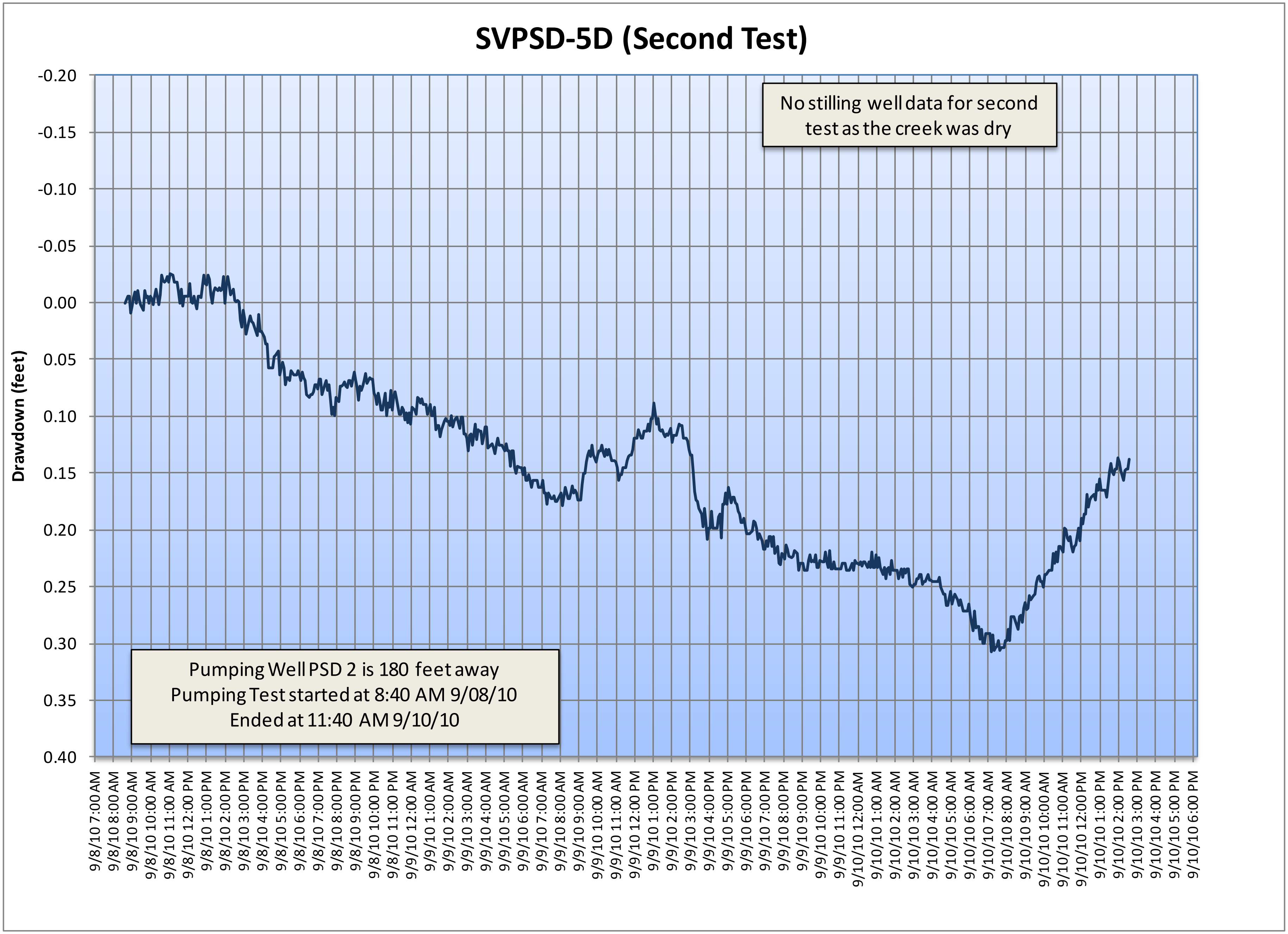
9/10/10 6:00 PM


SVPSD-5S (Second Test)

No stilling well data for second test as the creek was dry

Pumping Well PSD 2 is 180 feet away
Pumping Test started at 8:40 AM 9/08/10
Ended at 11:40 AM 9/10/10


SVPSD-5D (Second Test)
Drawdown (feet)
-0.20
-0.15
-0.10
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
No stilling well data for second test as the creek was dry
Pumping Well PSD 2 is 180 feet away
Pumping Test started at 8:40 AM 9/08/10
Ended at 11:40 AM 9/10/10
9/8/10 7:00 AM
9/8/10 8:00 AM
9/8/10 9:00 AM
9/8/10 10:00 AM
9/8/10 11:00 AM
9/8/10 12:00 PM
9/8/10 1:00 PM
9/8/10 2:00 PM
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9/9/10 3:00 AM
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9/9/10 2:00 PM
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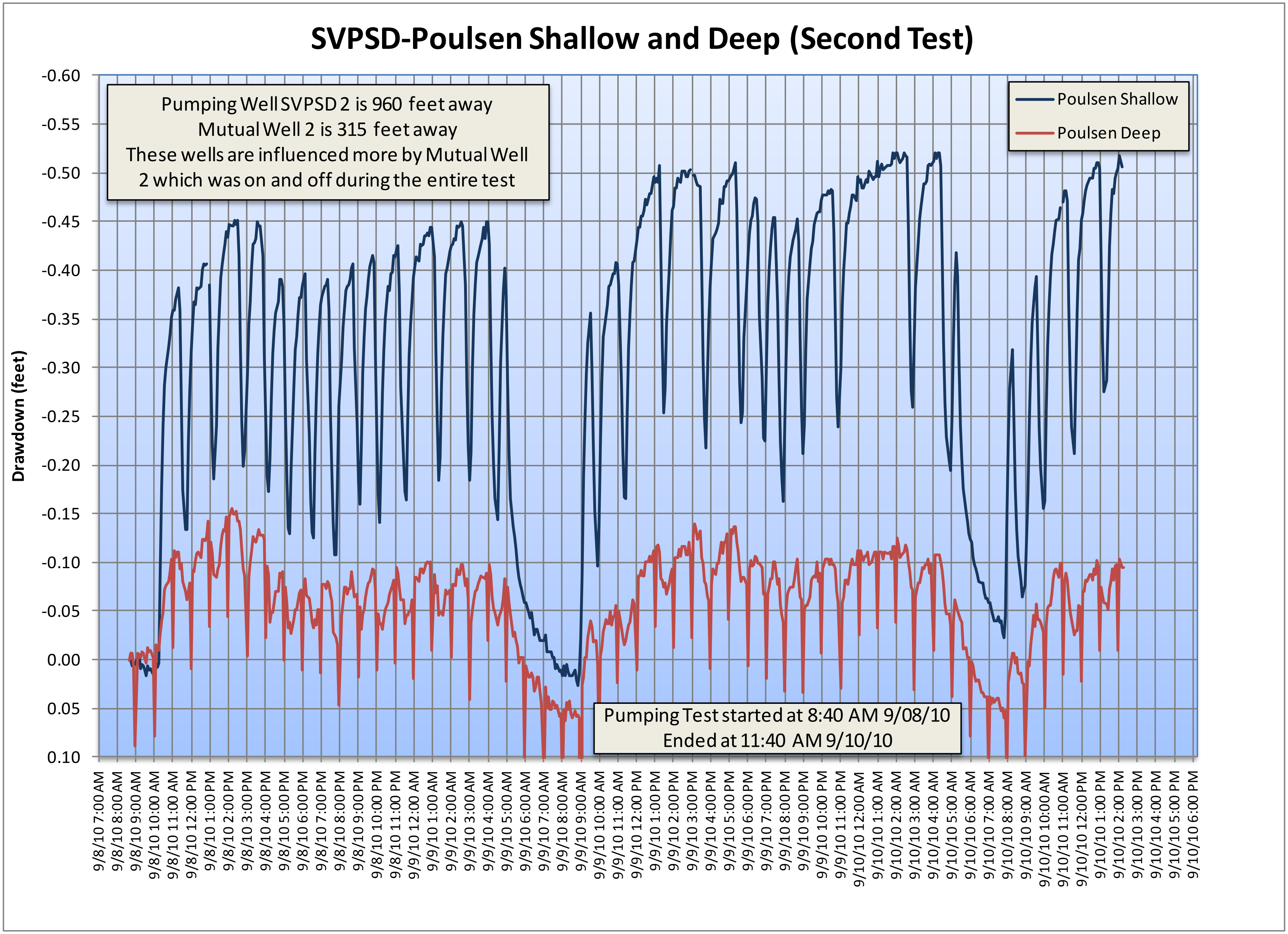

SVPSD-Poulsen Shallow and Deep (Second Test)

Pumping Well SVPSD 2 is 960 feet away
Mutual Well 2 is 315 feet away
These wells are influenced more by Mutual Well 2 which was on and off during the entire test

Pumping Test started at 8:40 AM 9/08/10
Ended at 11:40 AM 9/10/10

Task 4.1
Technical Memorandum on Seasonal Creek/Aquifer Interactions

Prepared for:
Squaw Valley Public Service District
November 2013

Prepared by:
HydroMetrics WRI

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Appendix A: Instrumentation Photographs
Appendix B: Survey Data
Appendix C: Streambed Temperature Data

LIST OF FIGURES

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ABBREVIATIONS

bgs	below ground surface
cfs	cubic feet per second
i	groundwater gradient
J/kg °C	joule per kilogram degree Celsius
K	hydraulic conductivity
kg/m^3	kilogram per cubic meter
m	meter
MSL	mean sea level
q	groundwater flow rate
SVPSD	Squaw Valley Public Service District
W/m °C	watts per meter degree Celsius

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SECTION 1
BACKGROUND AND PURPOSE

The Squaw Valley Creek/Aquifer Interaction Project was initiated in response to the State Water Resources Control Board's Resolution No. 2007-0008, which resolved to direct the Lahontan Water Board to continue supporting the efforts of entities pumping groundwater as well as other stakeholders in Squaw Valley to: (1) minimize effects on the creek, (2) develop a groundwater management plan that recognizes potential effects of pumping on the creek and seeks to minimize or eliminate adverse effects on Squaw Creek, and (3) conduct a study of potential interaction between groundwater pumping and flows in Squaw Creek.

Limited water supplies in Olympic Valley have resulted in a perceived competition between water needed for municipal and irrigation supplies, and water needed for environmental sustainability. Additionally, the channelization of Squaw Creek in the late 1950s by the Army Corp of Engineers improved drainage, but resulted in the unintended consequence of draining shallow groundwater away from the aquifer. This resulted in two problems. First the trapezoidal channel removes available groundwater that could provide in-stream flows later in the season. Second, the trapezoidal channel drains water away from the well field, reducing the available water for water supply.

The Squaw Valley Creek/Aquifer Interaction Project's overall goals are:

1. Improve and quantify our understanding of creek/aquifer interaction;
2. Diminish groundwater pumping impacts on Squaw Creek and the associated Truckee River; and
3. Increase groundwater storage in Olympic Valley.

An important aspect of the Squaw Valley Creek/Aquifer interaction study is quantifying seasonal and long-term Creek/Aquifer interactions using heat (temperature) as a tracer to track the movement of water between Squaw Creek and the underlying groundwater system. The flow between Squaw Creek and the underlying groundwater system can be quantified by analyzing six months of 15-minute interval temperature measurements from six probes that were installed in Squaw Creek. This memorandum presents the methodology, analysis results, and conclusion from the analysis of the temperature data.

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SECTION 2
METHODOLOGY

2.1 STUDY AREA DESIGN

The Seasonal Creek/Aquifer Interaction Study focused on the interaction between Squaw Creek and the underlying aquifer in the western portion of Olympic Valley. The western portion of the Valley has the greatest alteration to the natural flow system due to development, municipal pumping, and creek modification. The Seasonal Creek/Aquifer Interaction Study was conducted in a reach of Squaw Creek that has been deepened and straightened, is near the majority of the large capacity production wells, and is adjacent to an expansive paved parking lot.

Two locations in Squaw Creek's trapezoidal channel were outfitted with piezometers, stilling wells, and temperature probes. The upstream group is located in the section of the channel that is nearest well SVPSD-4R. This location is referred to as the Village East Bridge location in this report. This instrument group is not the easternmost group – it is named after the closest bridge which is called the Village East Bridge. The downstream instrument group is located near Squaw Valley Public Service District (SVPSD) wells MW-5D and MW-5S, and is referred to as the Papoose Bridge location. The locations of these instrument groups in relation to nearby pumping and monitoring wells are shown in Figure 1.

Each group of instruments includes several measuring devices; including stilling wells, shallow piezometers, and temperature probes.

- Stilling wells are used to measure water levels in Squaw Creek.
- Shallow piezometers measure shallow groundwater levels from depths of less than 10 feet below ground surface (bgs).
- Temperature probes measure shallow groundwater temperature at various depths.

The piezometers, stilling wells, and temperature probes were located together to allow us to correlate shallow groundwater elevations with groundwater flows through the streambed, and to infer hydraulic properties of streambed sediments. Several temperature probes and shallow piezometers were included at each measuring location to observe both spatial variation in Creek/Aquifer interactions, and variations with depth bgs.

Figure 1: Temperature Probe and Stream Piezometer Location

Cross-sections of each group of instruments are drawn in Figure 2 and Figure 3. These figures are drawn to scale in the vertical direction but not in the horizontal direction. The relative horizontal position of each instrument is approximate.

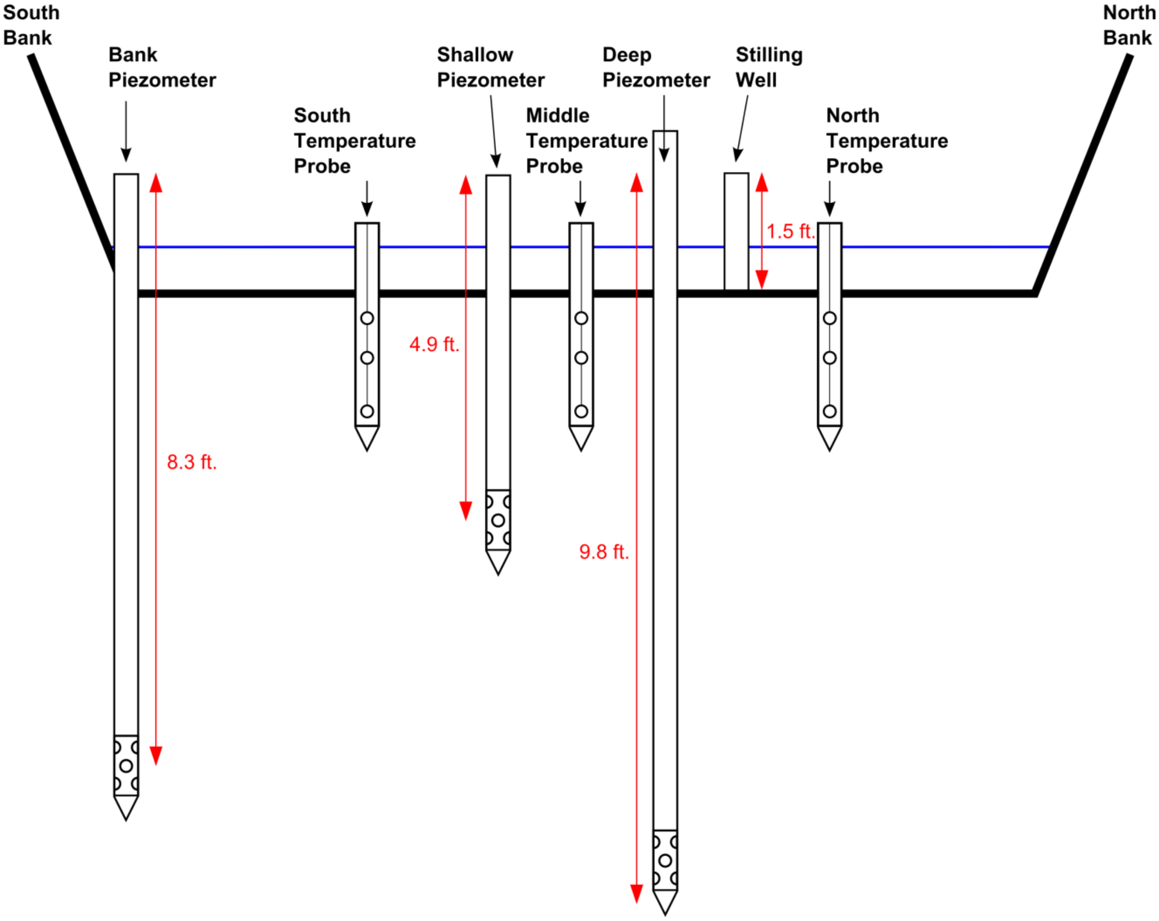

Figure 2: Cross-Section of Village East Bridge Instruments

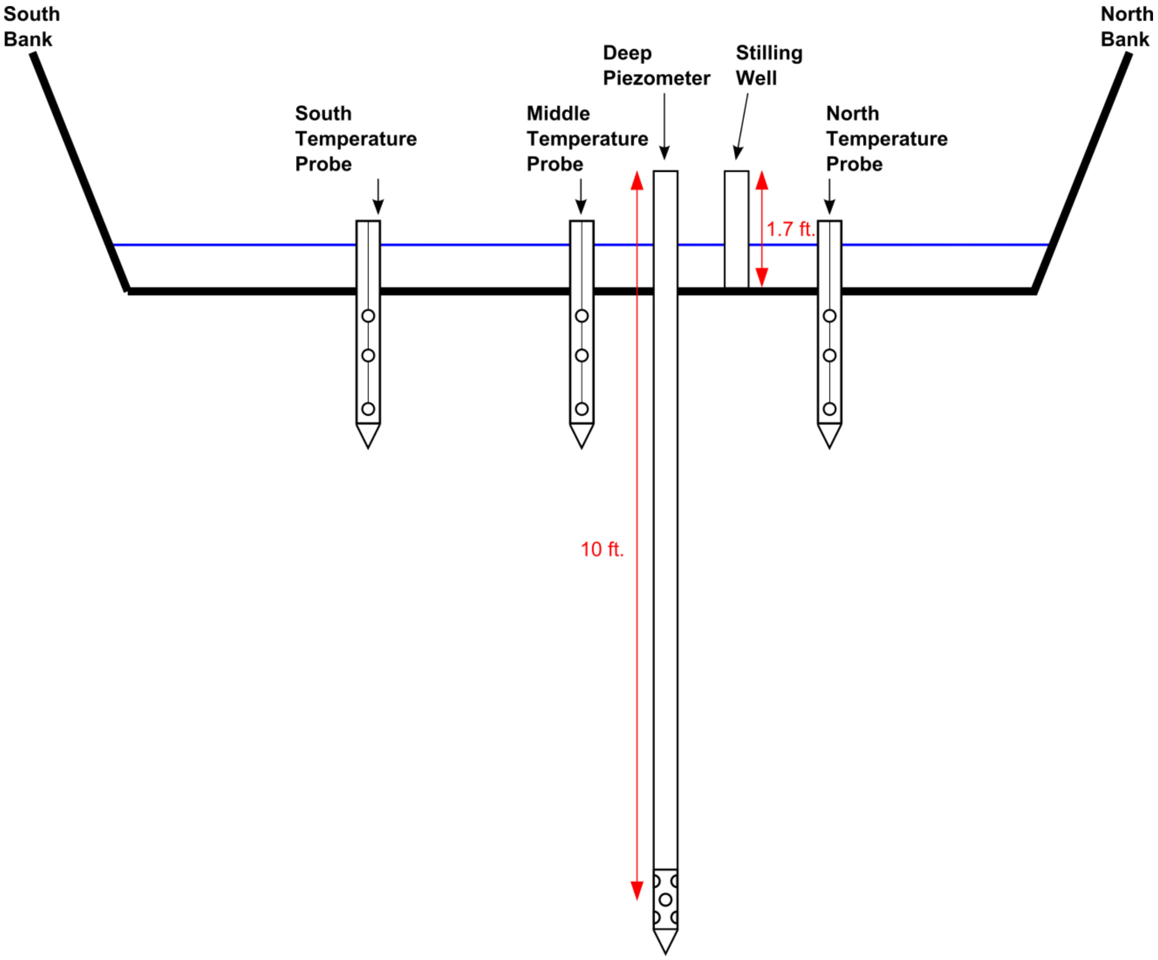

Figure 3: Cross Section of Papoose Bridge Instruments

2.2 TEMPERATURE PROBES

Six temperature probes were installed in Squaw Creek's trapezoidal channel on May 27, 2009. Three temperature probes were installed in the Creek at Village East Bridge and three probes were installed in the Creek at Papoose Bridge. Each group was aligned to transect the creek bed. Transects allowed us to capture the heterogeneity in the Creek, to produce representative estimates for the entire Creek width, and to guard against the danger of collecting a single set of unusable or anomalous data.

Although multiple probes were installed at each location, the probes did not span the entire width of the Creek. Along each transect the midpoint of the Creek was between the north and middle temperature probes, but closer to the northern temperature probe. Therefore, we estimated that along each transect the northern temperature probes reflect conditions in the northern 50% of the Creek width, the middle temperature probes reflect conditions in approximately 17% of the Creek width, and the south temperature probes reflect conditions in the southern 33% of the Creek width.

Temperature probes were based on a design provided by Dr. Andrew Fisher from the University of California, Santa Cruz (personal communication). The probes were designed to measure ambient groundwater temperature at three different depths below the streambed. This design has been developed to collect data that can be analyzed using the techniques outlined in Hatch et al. (2006). Although the technique outlined by Hatch (2006) requires temperature measurements from only two depths, the ideal depths and spacing of temperature measurements varies with hydrogeologic conditions. By installing three temperature sensors in each probe, we ensured that a wider range of possible hydrologic conditions could be analyzed. Details on the depth of the sensors in each temperature probe are shown on Table 1. A schematic showing the probe design is shown in Figure 4. The temperature probes were not surveyed, because all data analyses are referenced to distance below the streambed.

Table 1: Temperature Probe Construction Details

Temperature Probe	Depth to First Data Logger (cm bgs)	Depth to Second Data Logger (cm bgs)	Depth to Third Data Logger (cm bgs)
Village East Bridge – South	9.8	24.8	46.9
Village East Bridge– Mid	9.3	24.3	46.5
Village East Bridge– North	9.0	24.8	48.5
Papoose Bridge – South	10.0	25.4	47.1
Papoose Bridge – Mid	10.2	25.9	46.8
Papoose Bridge – North	11.0	25.8	47.3

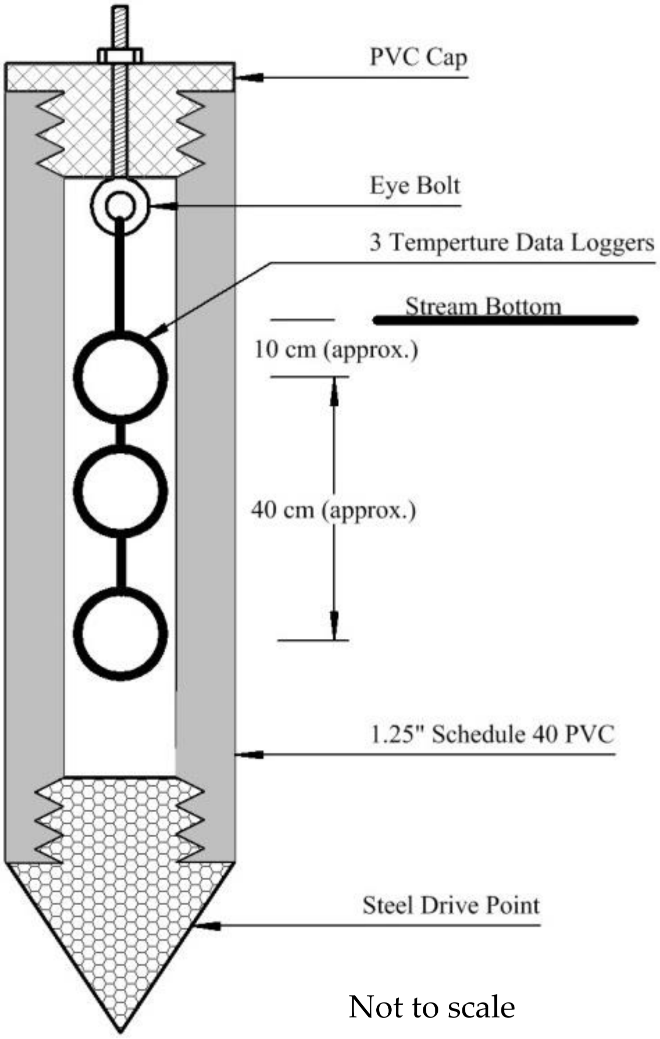

Figure 4: Temperature Probe Schematic

The data loggers were removed from the temperature probes on November 4, 2009 to prevent them from being lost in winter floods. Photos of the probes, probe installation, and probe removal are included in Appendix A.

2.3 IN-STREAM PIEZOMETERS AND STILLING WELLS

Three temporary piezometers were installed in the creek bed of Squaw Creek and one temporary piezometer was installed in the bank of Squaw Creek on June

3, 2009. Two creek bed piezometers and one creek bank piezometer were installed at the East Bank location. The one remaining creek bed piezometer was installed at the Papoose Bridge location. The piezometers were located adjacent to the temperature probes to promote coordinated analyses of temperature and water level data. Unlike the temperature probes, the piezometers were not installed in a transect to capture heterogeneity across the streambed.

The piezometers were constructed of ¾-inch threaded steel tubes. A screened drive point was threaded onto the end of each tube, and the piezometers were driven into the stream bottom with a slide hammer.

Stilling wells were installed at each of the instrument group sites to record water levels in Squaw Creek. Stilling wells were constructed of factory slotted 2-inch diameter PVC.

Each piezometer and stilling well was outfitted with a Micro-Diver® transducer with built-in data logger. The transducers had 10 meter ranges and 0.2 centimeter (cm) resolutions. A photo of the transducers is included in Appendix A. Table 2 lists the depth from the top of each piezometer to the center of the piezometer screen, and the distance from the top of each stilling well to the top of the creek bed.

Table 2: Piezometer and Stilling Well Lengths

Instrument	**Depth from instrument top to Center of Screen (feet)**
Papoose Bridge Deep Piezometer	10.0
Village East Bridge Shallow Piezometer	4.9
Village East Bridge Bank Piezometer	8.3
Village East Bridge Deep Piezometer	9.8
	Depth from instrument top to Creek Bed (feet)
Papoose Bridge Stilling Well	1.7
Village East Bridge Stilling Well	1.5

All temporary piezometers and stilling wells were surveyed by Andregg Geomatics on October 1, 2010 per GeoTracker guidelines and specifications. The horizontal location of the reference points were surveyed to the North American

Datum of 1983, California State Plane Coordinate System, Zone 2. The vertical elevation of the reference points were surveyed to within 0.01 foot precision, referenced to NGVD29. Survey data are summarized in Table 3. Complete survey data are included in Appendix B.

Table 3: Summary of Survey Data

Location	NORTHING	EASTING	ELEVATION
Stilling Well near 5D/5S; PVC Pipe	2203029.557	7063225.318	6187.75
Deep Piezometer near 5D/5S; Steel Pipe	2203029.545	7063225.202	6187.72
Stilling Well east of Bridge; PVC Pipe	2203137.427	7062661.918	6188.46
Shallow Piezometer east of Bridge; Steel Pipe	2203137.436	7062661.833	6188.53
Deep Piezometer east of Bridge; Steel Pipe	2203137.364	7062666.277	6188.59
Bank Piezometer east of Bridge; Steel Pipe	2203128.635	7062663.611	6188.55

Notes:
NAD83 - California State Plane Coordinates Zone 2 - US Survey Feet
NGVD29 - Based on BM H-172 (PID KS0274) EL: 6177.99

The Micro-Diver® transducers were removed from the piezometers and stilling wells on November 4, 2009 to prevent them from being lost in winter floods.

2.4 MEASUREMENT PERIODS AND FREQUENCY

Time periods when data were collected from the piezometers and temperature probes are summarized in Table 4. Table 4 also summarizes the monitoring frequency for the Micro-Diver data loggers and temperature loggers.

Table 4: Data Record Periods

Data Type	Begin Date	End Date	Frequency
Stream Piezometers Water Level	6/22/2009	11/4/2009	5 min.
Stilling Wells Water Level	6/22/2009	9/13/2009	5 min.
Streambed Temperature	5/23/2009	11/4/2009	15 min

SECTION 3
RESULTS AND DISCUSSION

3.1 STREAMBED TEMPERATURE RESULTS

Temperature results from all six temperature probes are plotted in Appendix C. Results from the south probe at the Village East Bridge site are included as an example in Figure 5. Temperatures from each of the three depths are plotted on Figure 5 for comparison. The diurnal cycle, with temperature peaks in the midday and troughs during the early morning is the dominant signal seen in Figure 5. The amplitude of the diurnal signal decreases with increasing depth, and is apparent at all three measurement depths. For most of the record there is also a slight but observable phase shift between sensors.

A period was identified during the summer months when the temperature data suggest that the sediment around the probes is dry. Strong temperature oscillations and high average temperatures during the warm season indicate that the temperature sensors are recording air temperature fluctuations, and are no longer surrounded by water. The period between 7/15/2009 and 9/29/2009 was identified as a dry period for all probes; and the analysis of seepage and vertical conductivities was not performed for this period. The onset of dry behavior was gradual for most probes and the initial date was selected based upon the sudden amplitude increases seen in the southernmost Village East Bridge probe. The end of the dry period was chosen to be the first of three abrupt changes in behavior seen in all probes between 9/29/2009 and 10/15/2009.

Figure 6 plots measured streamflow in Squaw Creek upstream and downstream of the probes, and precipitation from the Nova Lynx gage. Precipitation is graphed as positive in the downward direction: greater precipitation results in longer bars hanging from the top of Figure 6. Streamflow data came from the three stream gauges monitored by Friends of Squaw Creek. The upstream gauges first recorded no streamflow on 8/9/2009: almost a month later than the dry period identified from the temperature data (Figure 5).

There are several reasons why it is plausible for the temperature probes to indicate dry sediment conditions while the stream gages and stilling wells continue to record streamflows. Before the temperature probes indicated dry sediments, the streamflows had been low and declining gradually. During such low flows, the Creek only covers a fraction of the channel width. This narrow and likely braided stream would not necessarily flow directly over the temperature probes. Therefore, while sediments directly beneath the flowing creek might remain saturated, sediments around the temperature probes would dry out. In addition, recharge rates from low streamflows may not be sufficient to maintain saturated conditions directly beneath the flowing creek: unsaturated sediments likely developed even when there was some water flowing down from the stream, into the sediments around the probes. The fact that the temperature data are not perfect indicators of streamflow should be considered when interpreting results.

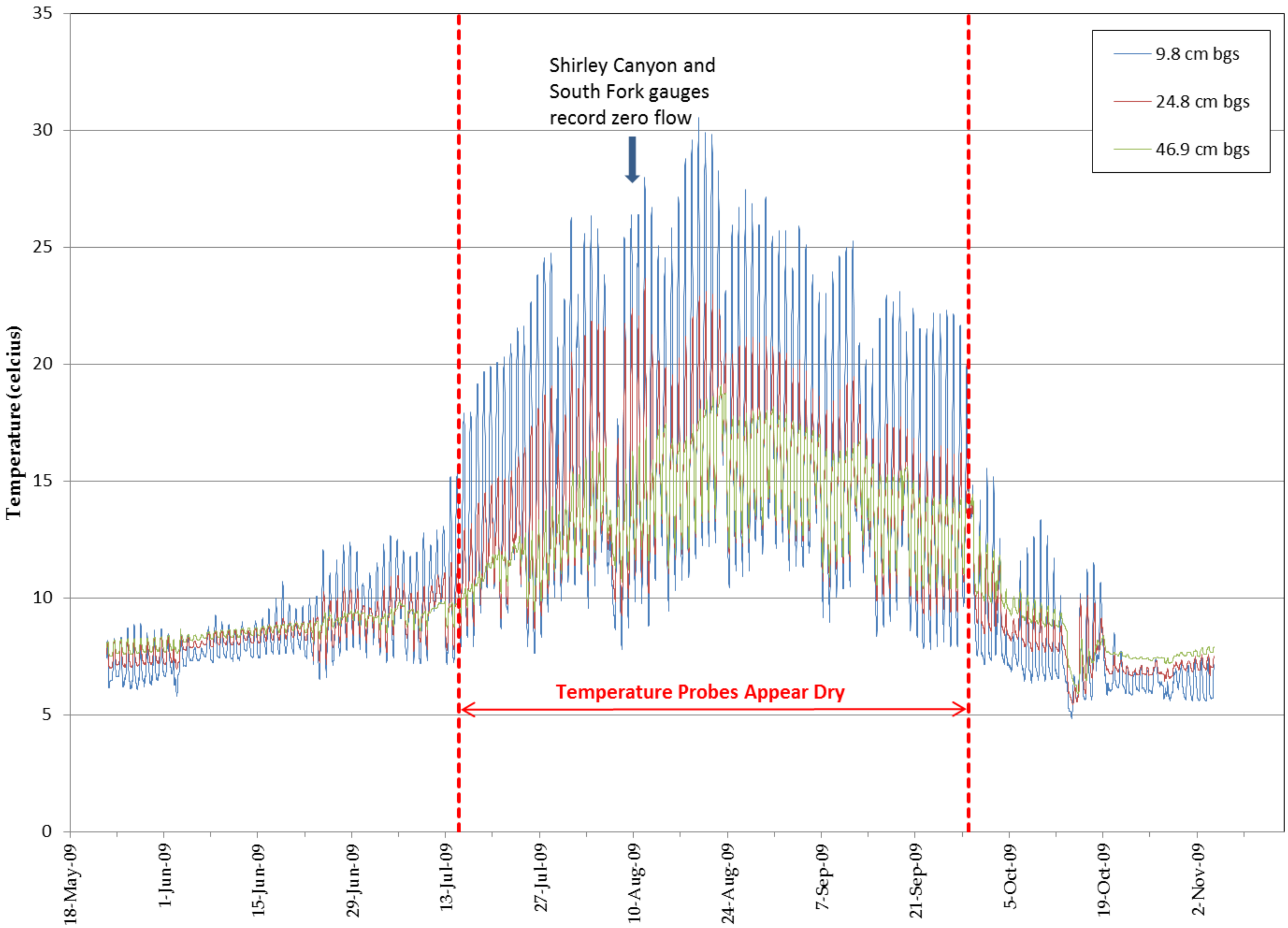

Figure 5: Village East Bridge South Temperature Probe

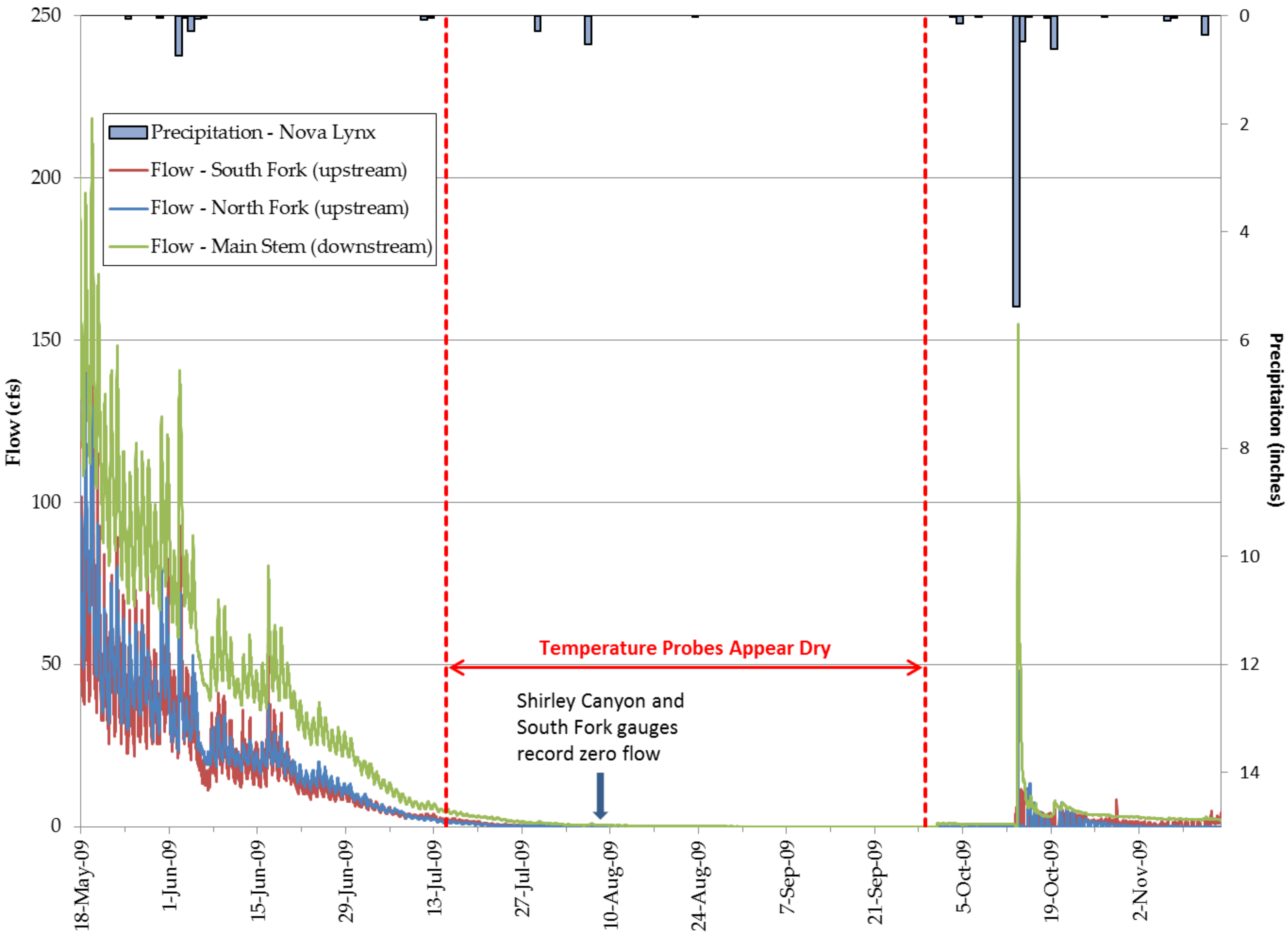

Figure 6: Precipitation and Streamflow for Squaw Valley

The temperature data were analyzed to estimate vertical seepage velocities in and out of Squaw Creek; hydraulic gradients between Squaw Creek and the surrounding aquifer; and the vertical hydraulic conductivity of the sediments directly below Squaw Creek. Vertical seepages, or fluxes, are a direct measurement of the amount of water flowing into or out of Squaw Creek from the surrounding aquifer. Hydraulic gradients are necessary to estimate vertical hydraulic conductivities of Squaw Creek's bed. The vertical hydraulic conductivity of the streambed directly below Squaw Creek is necessary for updating the Squaw Valley groundwater model.

3.2 VERTICAL SEEPAGE VELOCITIES

Vertical groundwater seepage velocities into and out of Squaw Creek were estimated from temperature data using the method of Hatch et al. (2006). This method uses heat as a tracer of seepage through the streambed. The method solves for the vertical groundwater velocity between a pair of temperature sensors by observing changes in the amplitude and phase shift of the daily thermal waves as they penetrate downward into the streambed. The method is most accurate when fluid seepage rates are constant or varying slowly. Both upward and downward flow can be estimated.

The method requires that the raw temperature data be filtered to isolate daily temperature fluctuations. Interpreting the filtered signal requires some estimates of streambed thermal properties and hydrogeologic properties. Relevant values assumed for the streambed thermal properties and the data filters are listed in Table 5.

Table 5: Streambed Parameters and Filter Specifications

Parameter	Value	Units
Thermal Conductivity	1.55	W/m °C
Transverse Dispersivity	0.001	m
Longitudinal Dispersivity	0.001	m
Density of Fluid	996.5	kg/m^3
Heat Capacity of Fluid	4179	J/kg °C
Density of Solid Grains	2650	kg/m^3
Heat Capacity of Solid Grains	800	J/kg °C
Total Porosity	0.4	-

We chose to analyze the temperature data for the shallowest pair of sensors in each probe. Any set of two probes could be used for the analysis, but shallow sensors offer several advantages. First, the amplitude of temperature oscillations decreases with depth below the streambed, so shallower sensors generally have a greater daily signal. Second, shallower sensors tend to respond more quickly to changes in streambed conditions. Vertical seepage velocities were calculated for both the spring and fall periods, when the temperature probes did not appear to be surrounded by unsaturated sediments (Figure 5).

3.2.1 VILLAGE EAST BRIDGE RESULTS

The seepage velocity estimates from the three Village East Bridge probes are shown on Figure 7. These values are of vertical groundwater velocity, not rates of flux. In Figure 7, negative velocities equate to water flowing from Squaw Creek into the surrounding aquifer; positive velocities equate to water flowing from the surrounding aquifer into Squaw Creek. Observations of interest are noted below:

- Seepage velocities fall within the valid range of values for this method.
- Seepage velocities vary in magnitude and direction between probes.
- When streamflows are higher and groundwater elevations are higher there is greater variation in seepage velocity, with a general upward flow direction.
- Seepage velocity estimates converge towards zero around the dry period, with a general downward flow direction.

- A strong and consistent downward flow is seen in all probes immediately following the October 13 storm shown on Figure 6.

Seepage velocities from the three probes were combined to produce a single value for the entire streambed. A weighted mean was calculated assuming that the northern probe represented 50% of the width, the middle probe 17% of the width, and the southern probe 33% of the width. These results are shown in Figure 8. Seepage velocities were converted to volumetric flow rates (in cfs) by applying them to a representative section of Squaw Creek, with a width of 25 feet, a length of 1000 feet, and an effective porosity of 0.30 (McWhorter and Sunada, 1977). Table 6 presents seepage velocities and flow rates into and out of Squaw Creek near the Village East Bridge site for the periods before and after the probes appeared dry.

Table 6: Village East Bridge Seepage Results

Analysis Period	Statistic	Seepage Velocity (ft./day)	Flow Rate of 25ft x 1000ft Reach (cfs)	Date
Before Probes Appear Dry	Maximum Downward	-0.47	-0.041	6/24/2009
	Maximum Upward	2.08	0.180	6/10/2009
	Average	0.28	0.024	
After Probes Appear Dry	Maximum Downward	-1.77	-0.154	10/16/2009
	Maximum Upward	1.60	0.139	10/30/2009
	Average	0.23	0.020	

3.2.2 PAPOOSE BRIDGE RESULTS

The seepage velocity estimates from the three Papoose Bridge probes are displayed on Figure 9 These values are of vertical groundwater velocity, not rates of flux. In Figure 9, negative velocities equate to water flowing from Squaw Creek into the surrounding aquifer; positive velocities equate to water flowing from the surrounding aquifer into Squaw Creek.

- Seepage velocities fall within the valid range of values for this method.
- Seepage velocities vary in magnitude and direction between probes, with a downward flow observed at almost all times.

- When streamflows are higher and groundwater elevations are higher there is greater variation in seepage velocity.
- Seepages in the middle and north probe converge towards -1 ft/day around the dry period.
- A strong downward flow is seen in the south probe immediately following the October 13 storm shown on Figure 6. The response to the storm is less pronounced in the other two temperature probes.

Seepage velocities from the three probes were combined to produce a single value for the entire streambed. A weighted mean was calculated assuming that the northern probe represented 50% of the width, the middle probe 17% of the width, and the southern probe 33% of the width. These results are shown in Figure 10. Seepage velocities were converted to volumetric flow rates (in cfs) by applying them to a representative section of Squaw Creek, with a width of 25 feet, a length of 1000 feet, and effective porosity of 0.30 (McWhorter and Sunada, 1977). Table 7 presents seepage velocities and flow rates into and out of Squaw Creek near the Papoose Bridge site for the periods before and after the probes appeared dry. At this location, the weighted mean flux is always downward, from the Creek into the aquifer. Therefore, minimum and maximum downward seepage is presented rather than maximum upward seepage and maximum downward seepage.

Table 7: Papoose Bridge Seepage Results

Analysis Period	Statistic	Seepage Velocity (ft./day)	Flow Rate of 25ft x 1000ft Reach (cfs)	Date
Before Probes Appear Dry	Maximum Downward	-3.07	-0.267	5/28/2009
	Minimum Downward	-0.34	-0.029	6/23/2009
	Average	-1.03	-0.089	
After Probes Appear Dry	Maximum Downward	-2.46	-0.213	10/16/2009
	Minimum Downward	-0.56	-0.048	10/24/2009
	Average	-1.11	-0.097	

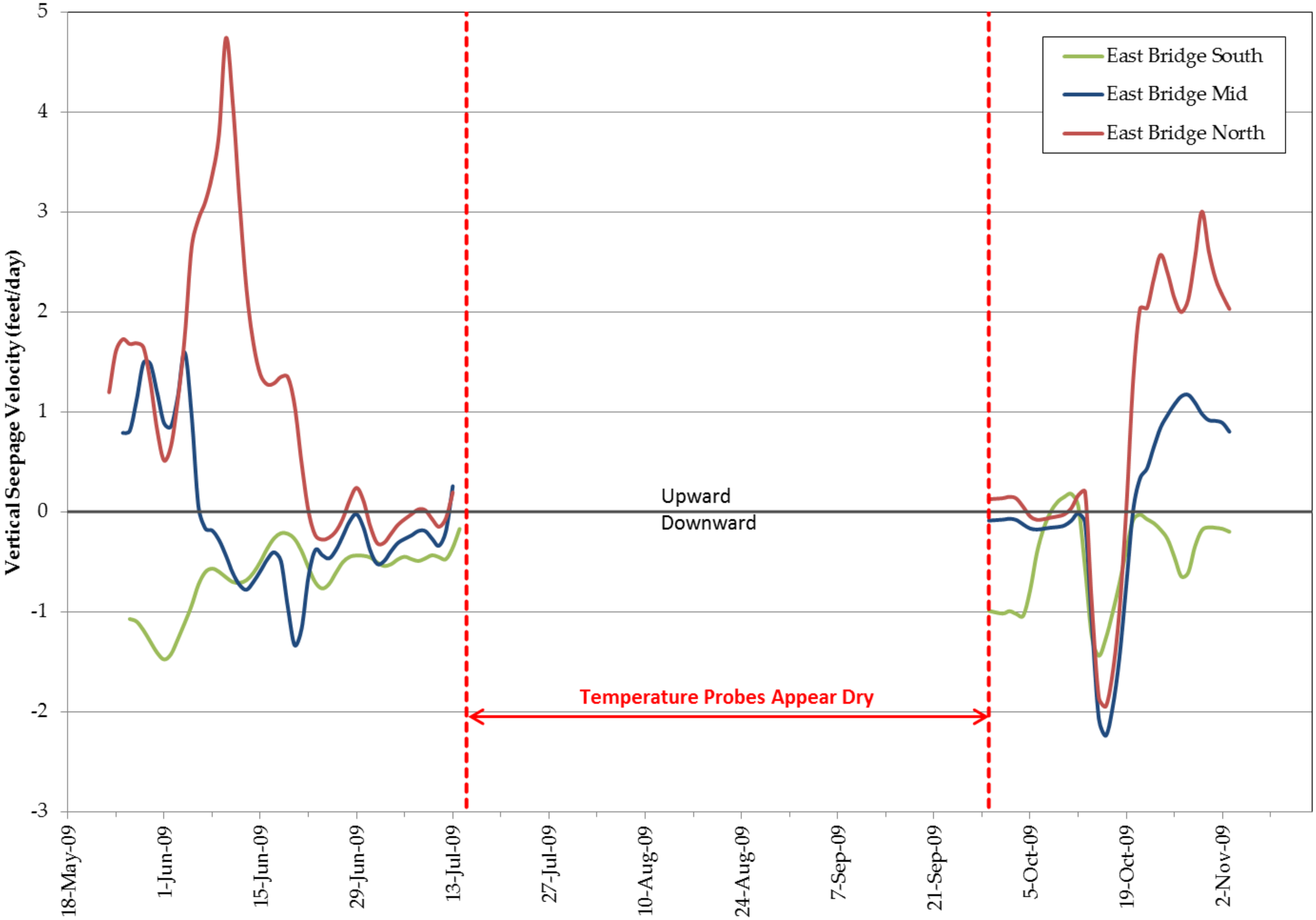

Figure 7: Village East Bridge Streambed Seepage Velocity

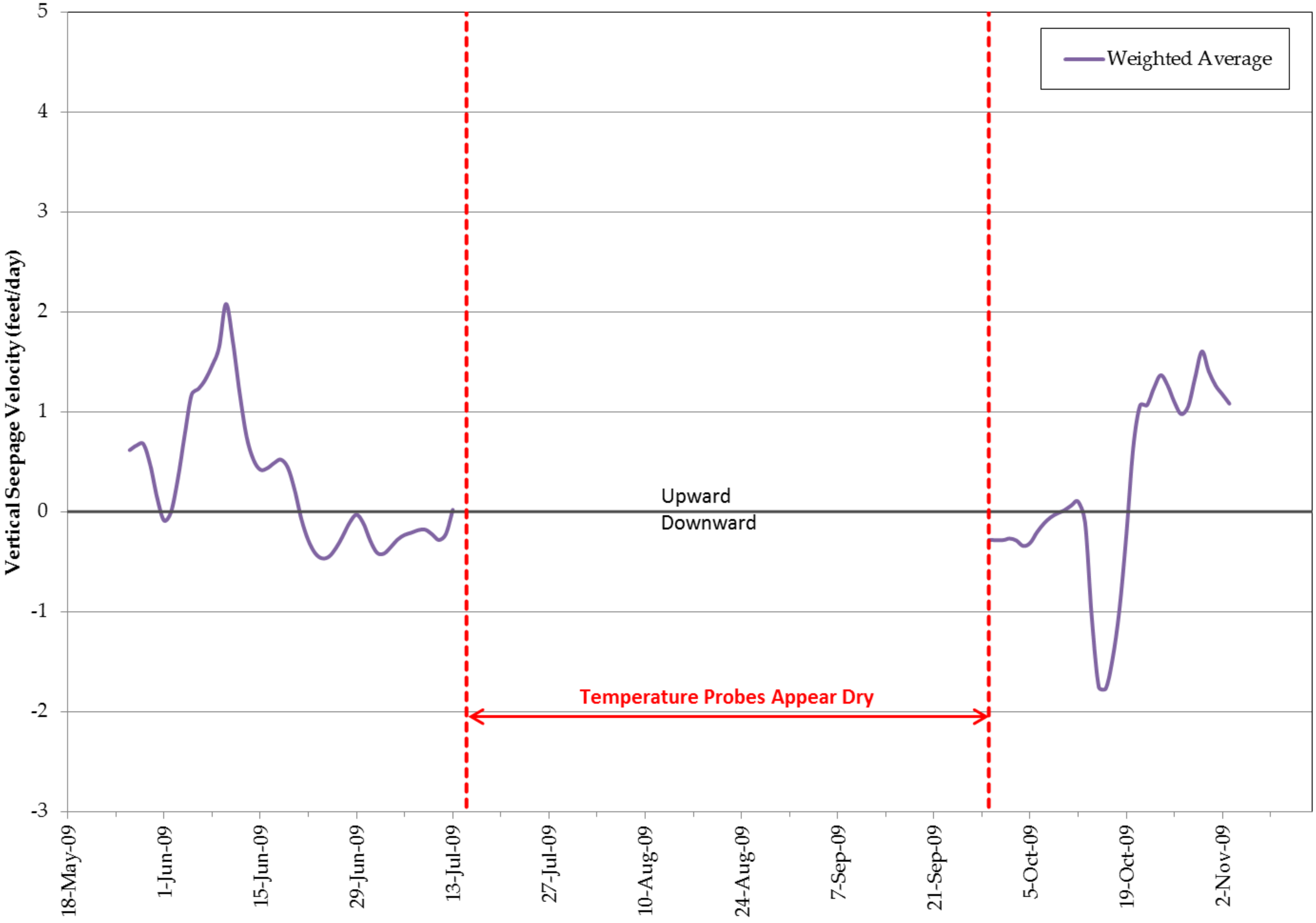

Figure 8: Village East Bridge Weighted Mean Streambed Seepage Velocity

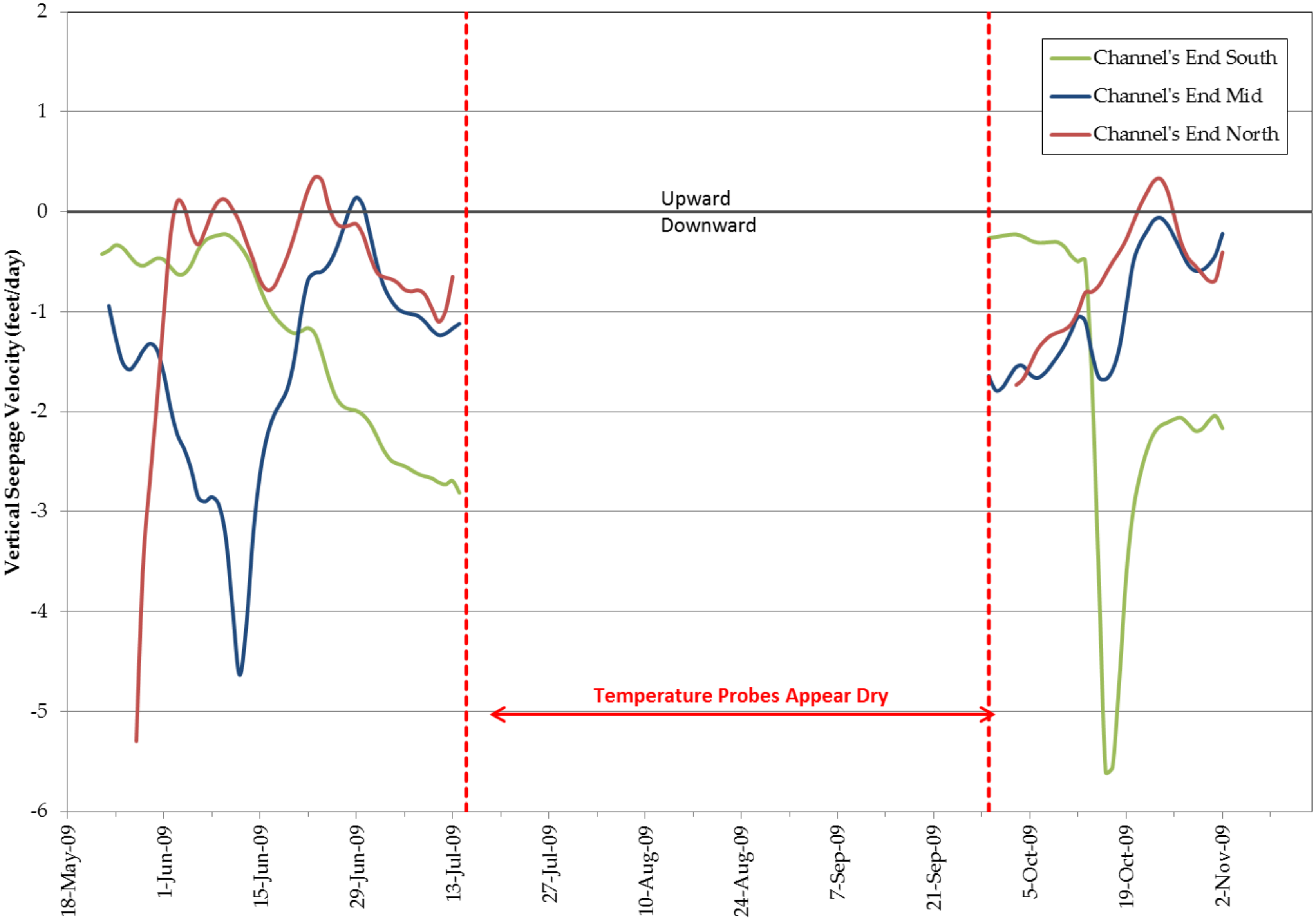

Figure 9: Papoose Bridge Streambed Seepage Velocity

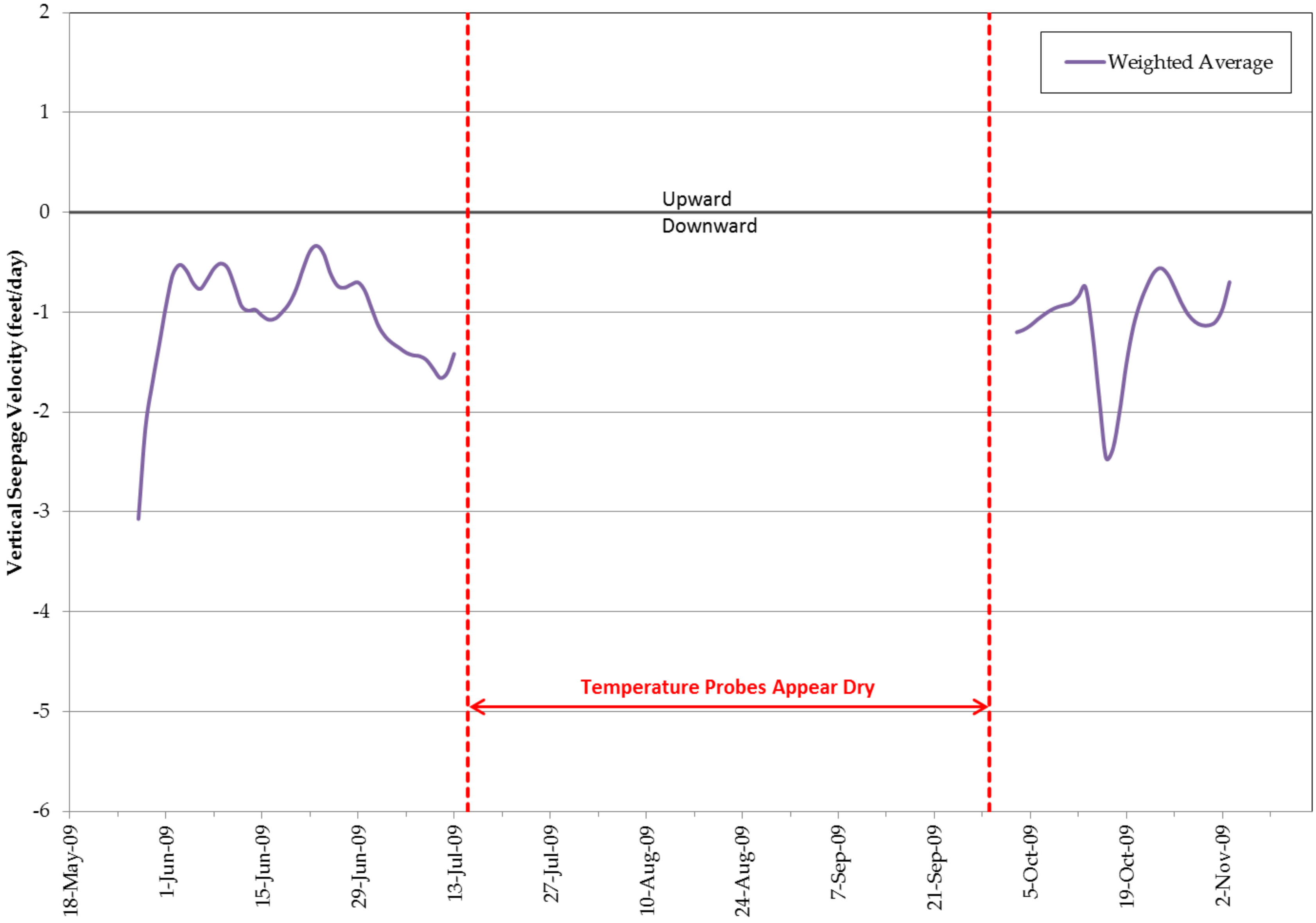

Figure 10: Papoose Bridge Weighted Mean Streambed Seepage Velocity

3.3 WATER LEVELS AND GRADIENTS

Creek water levels were recorded in the two stilling wells between June 22, 2009 and September 13, 2009. Groundwater levels were recorded in the four piezometers between June 22, 2009 and November 4, 2009. The water level data are plotted on Figure 11 and Figure 12. These data are consistent with the patterns observed in the temperature, streamflow, and precipitation record. The following notable behavior is seen in the water level data:

1. Groundwater elevations and Creek water levels gradually decline during the late spring as streamflow declines. This gradual decline continues after the temperature probes appear to be surrounded by dry sediments, demonstrating that the temperature probes are not a good indicator of when low creek flows end.

2. Heads decline at a greater rate immediately after the stream gauges go dry. This indicates that the aquifer in late spring and early summer is supported by runoff and streamflow. Soon after runoff ends, groundwater levels drop due to reduced recharge.

3. Groundwater elevations in the Village East Bridge shallow piezometer are lower than the creek water level measured in the stilling well from June 22, 2009 until the creek goes dry (Figure 11). This indicates that water generally flows from the Creek into the aquifer after June 22, 2009. This is consistent with the seepage velocities shown in Figure 8.

4. Groundwater elevations in the Papoose Bridge deep piezometer are lower than the creek water level measured in the stilling well from June 22, 2009 until the creek goes dry (Figure 12). This indicates that water generally flows from the Creek into the aquifer after June 22, 2009. This is consistent with the seepage velocities shown in Figure 9.

5. Groundwater elevations in the Village East Bridge deep piezometer are higher than the groundwater elevations in both the Village East Bridge shallow piezometer and stilling well. This suggests that immediately adjacent to Squaw Creek, the deep aquifer is being recharged by mountain front recharge and possibly fracture flow, either in addition to or in lieu of recharge from the creek.

6. Groundwater elevations recover abruptly with the large October 13 storm shown on Figure 6. Groundwater elevations in all piezometers rise quickly to the Creek bed elevation. This suggests the groundwater basin filled almost immediately after the October 13 storm, and that there is a strong hydrologic connection between the creek and aquifer.

The combination of groundwater levels in the piezometers and water levels measured in the stilling wells provide site specific data that can be used to estimate vertical groundwater gradients in the shallow sediments directly beneath Squaw Creek. At the Papoose Bridge location, the deep piezometer and stilling well data are used for to calculate vertical gradients because they are the only water levels available at this location. At the Village East Bridge location, the shallow piezometer and stilling well are used to calculate vertical gradients because they cover depths closest to the depths of the temperature probes.

Two important checks were made on each pair of water level data. The patterns of head variation at each depth were compared to ensure that a hydraulic connection exists between the measurement depths. In both pairs of sensors, the stilling wells and piezometers have similar patterns of water level variations, suggesting that there is a hydraulic connection. The connection is more evident at the Village East Bridge location than at the Papoose Bridge location. The water levels were also compared to ensure that the gradients between them are not too small. Small gradients can lead to large errors in the hydraulic conductivity estimates. In both cases, small values are only seen during a brief period in the early record when gradients are switching direction.

Hydraulic gradients are calculated for each location and shown on Figure 13 and Figure 14. Positive numbers indicate gradients that drive water from the Creek into the aquifer, and negative numbers indicate gradients that drive water from the aquifer into the Creek. A moving average was taken to smooth the data using a window of five days.

Vertical gradients shown on Figure 13 and Figure 14 are only negative for a few times early in the measurement period, suggesting water generally flows from Squaw Creek into the aquifer after June 22, 2009. This is consistent with the vertical flow data shown on Figure 8 and Figure 9. Significant upward flow into Squaw Creek only occurred prior to June 22, 2009, and is therefore not shown in the vertical gradient data.

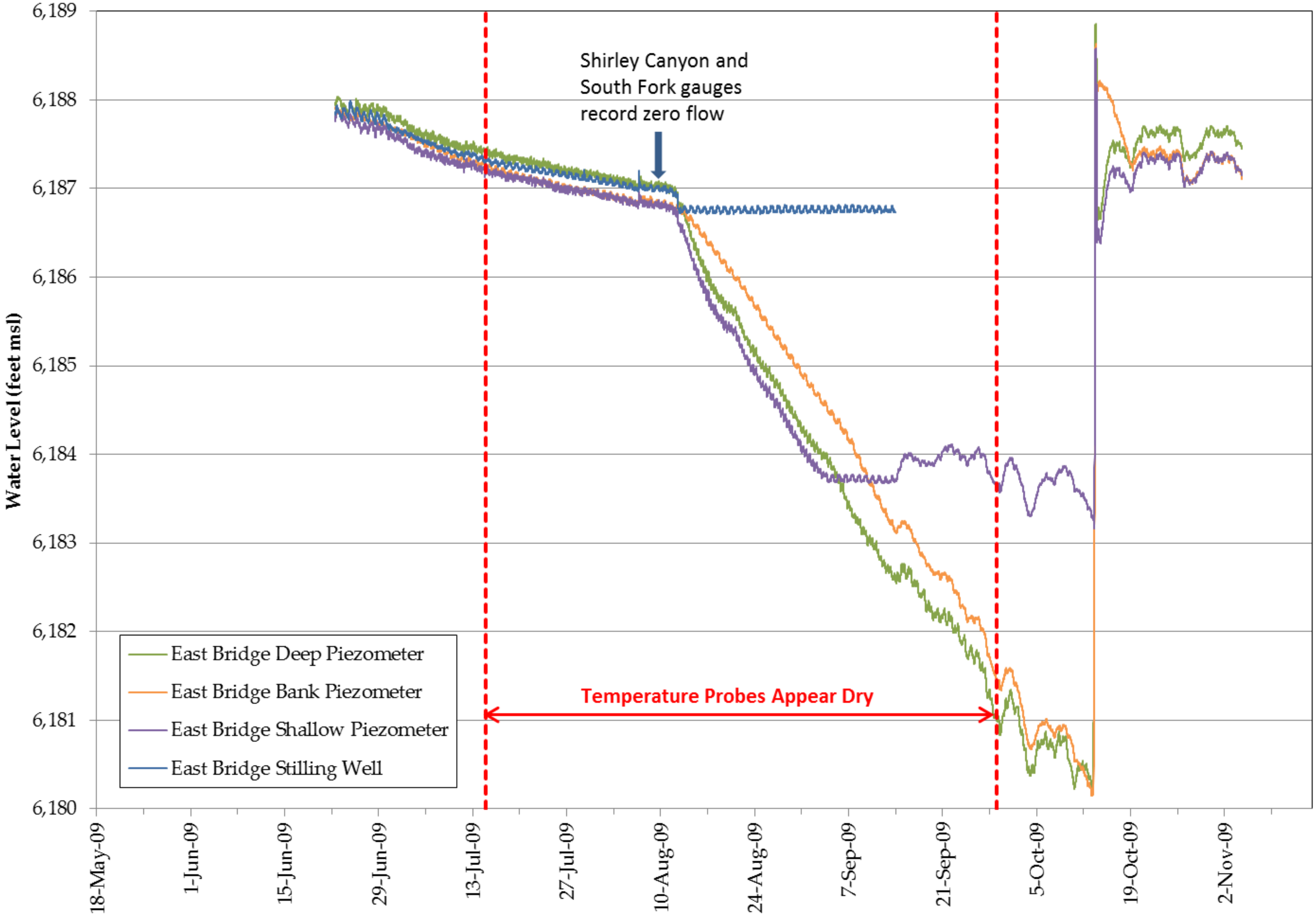

Figure 11: Village East Bridge Water Level Data

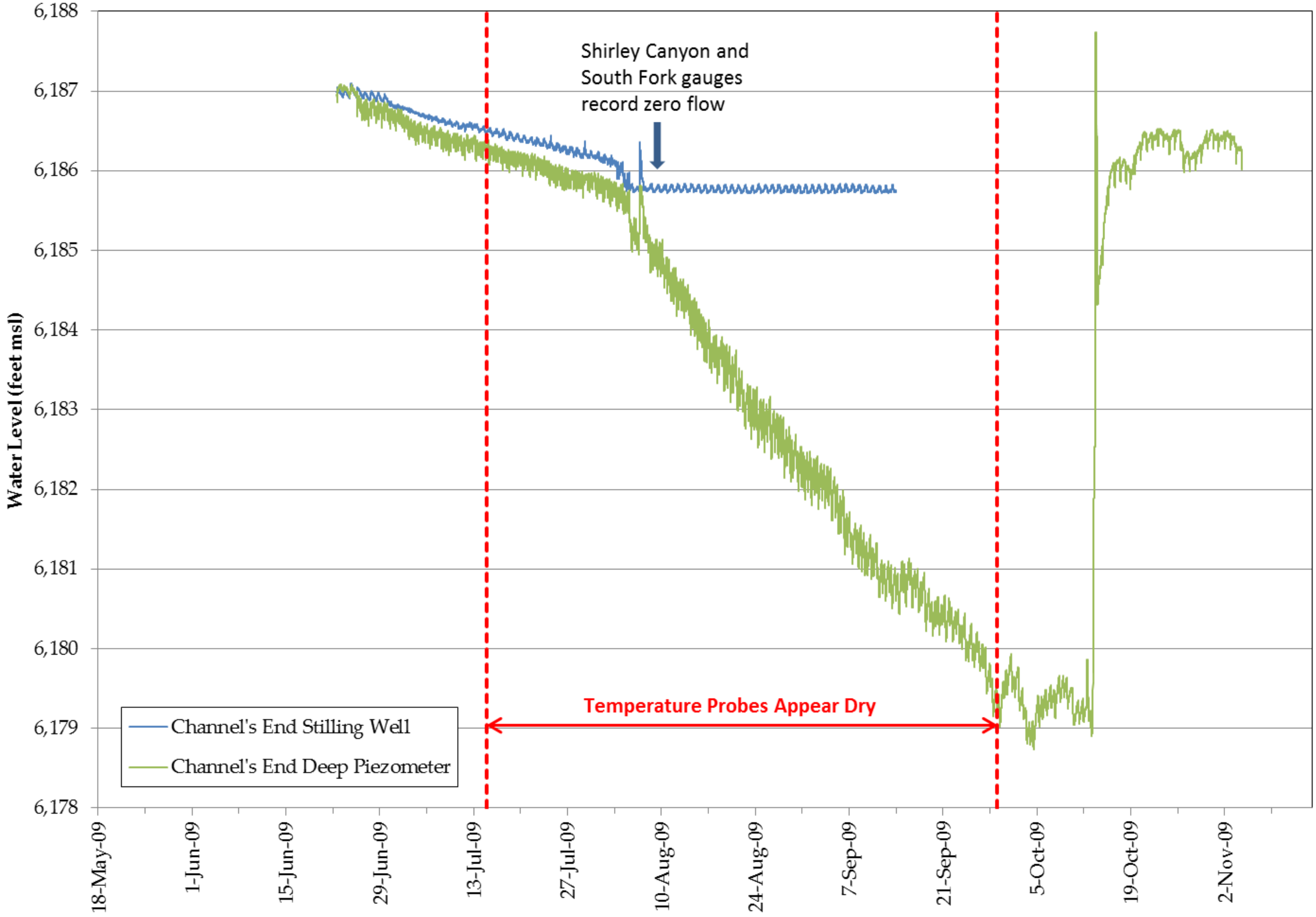

Figure 12: Papoose Bridge Water Level Data

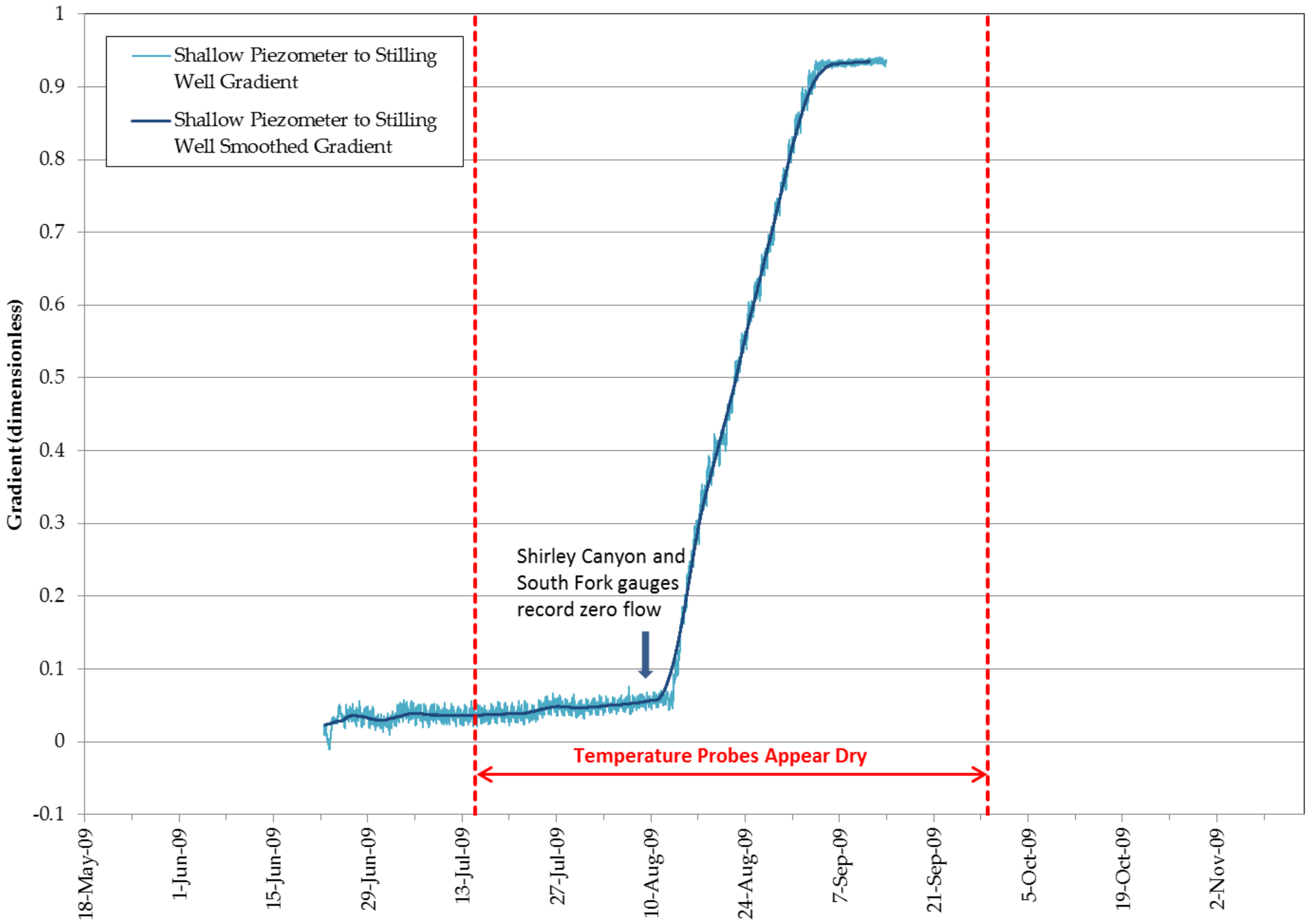

Figure 13: Village East Bridge Hydraulic Gradient

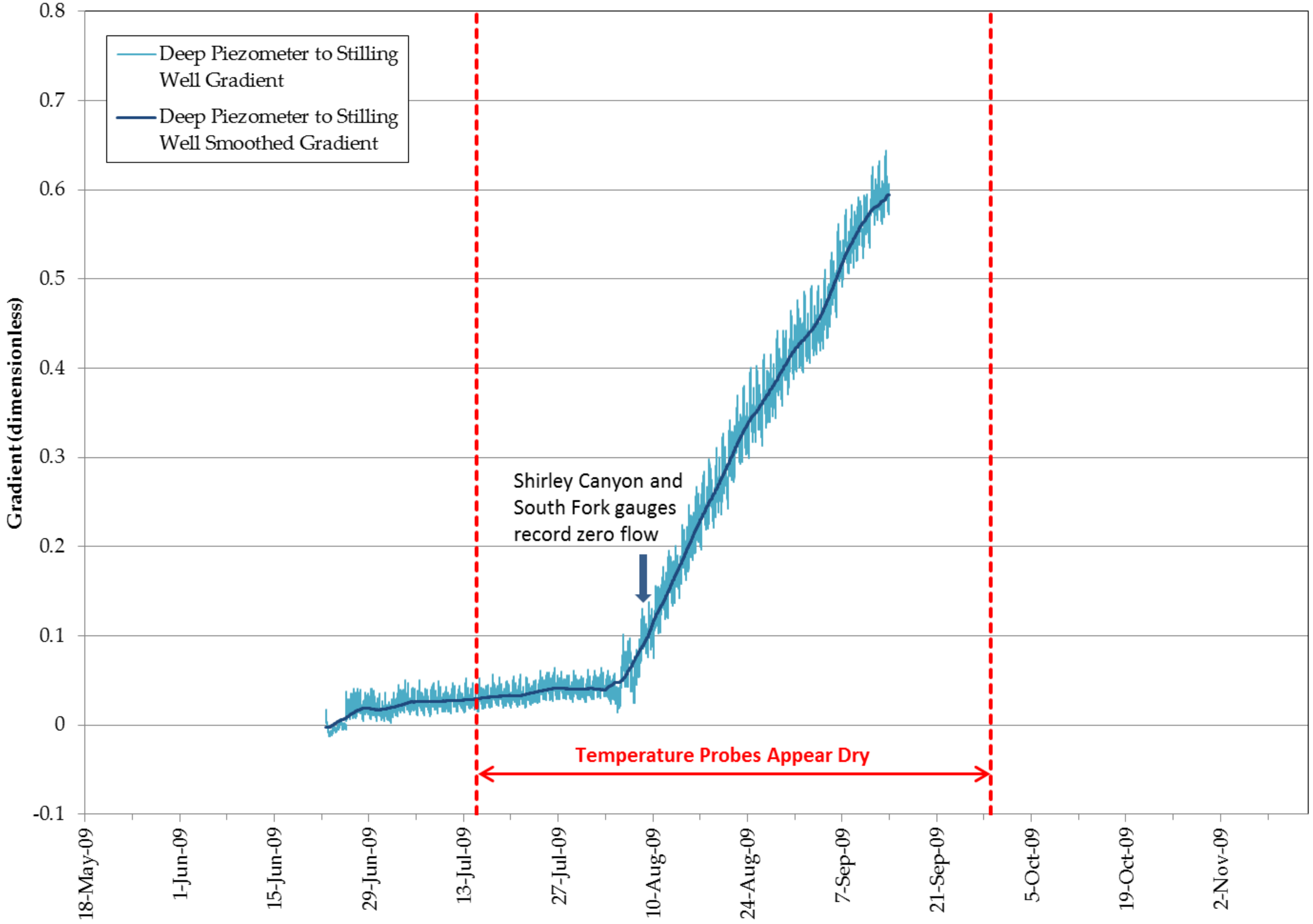

Figure 14: Papoose Bridge Hydraulic Gradient

3.4 VERTICAL HYDRAULIC CONDUCTIVITIES

Vertical hydraulic conductivities were calculated for each temperature probe using Darcy's Law and the previously calculated values of vertical seepage and hydraulic gradient. Darcy's Law states:

$$q = K \times i$$

Where:

- q is a seepage flux rate obtained by multiplying the vertical seepage velocity calculated in Section 3.2 and the effective porosity 0.3;
- i is the hydraulic gradient calculated in Section 3.3; and
- K is the vertical hydraulic conductivity that we are solving for.

The daily seepage values were combined with the 5-minute gradient values by selecting one representative daily gradient. Vertical hydraulic conductivity values could only be calculated for the period between 6/23/2009 and 7/14/2009 when values of both seepage and hydraulic gradient were available.

The calculated vertical conductivity estimates are shown in Figure 15 and Figure 16. Plots of seepage and gradient are shown on these figures for comparison. Hydraulic conductivity is plotted on a logarithmic scale on both of these figures. Any calculations that suggested a negative hydraulic conductivity are not shown. In both Figure 15 and Figure 16 the hydraulic gradients are relatively steady compared to seepage rates, which indicates that apparent variations in seepage are responsible for the apparent variations in hydraulic conductivity estimates.

At the Village East Bridge location, conductivity values are positive for most times and at most locations (Figure 15). This indicates that the seepage rates inferred with thermal data are consistent with head gradients measured independently. Calculated conductivity values are only reported when the direction of the seepage and gradient are consistent. Values are fairly steady through the time of analysis, with median values of about 3 feet/day, maximum values around 5-10 feet/day, and minimum values around 0 feet/day. The conductivities appear to vary through time in a similar fashion at all three probe locations, with the highest values seen in the south temperature probe, middle values seen in the middle temperature probe and lowest values seen in the north temperature probe. The middle probe was installed closest to the stilling well and shallow piezometer that were used to determine the gradient. Therefore, calculations of conductivity based on thermal data from the middle probe are considered to be the most accurate.

At the Papoose Bridge location, conductivity values are positive for most times and at most locations. Extreme values are seen during the first two weeks but quickly come towards reasonable values where they remain for the rest of the analysis period. Median values are about 15 feet/day, maximum values around 40-60 feet/day, and minimum values around 0 feet/day. The conductivities appear to vary through time in a similar fashion at the north and middle probes, with the south probe behaving differently. Values at the south probe are at least 2 times greater than at the other probes. The middle probe was installed closest to the stilling well and deep piezometer that were used to determine the gradient. Therefore, calculations of conductivity based on thermal data from the middle probe are considered to be the most accurate.

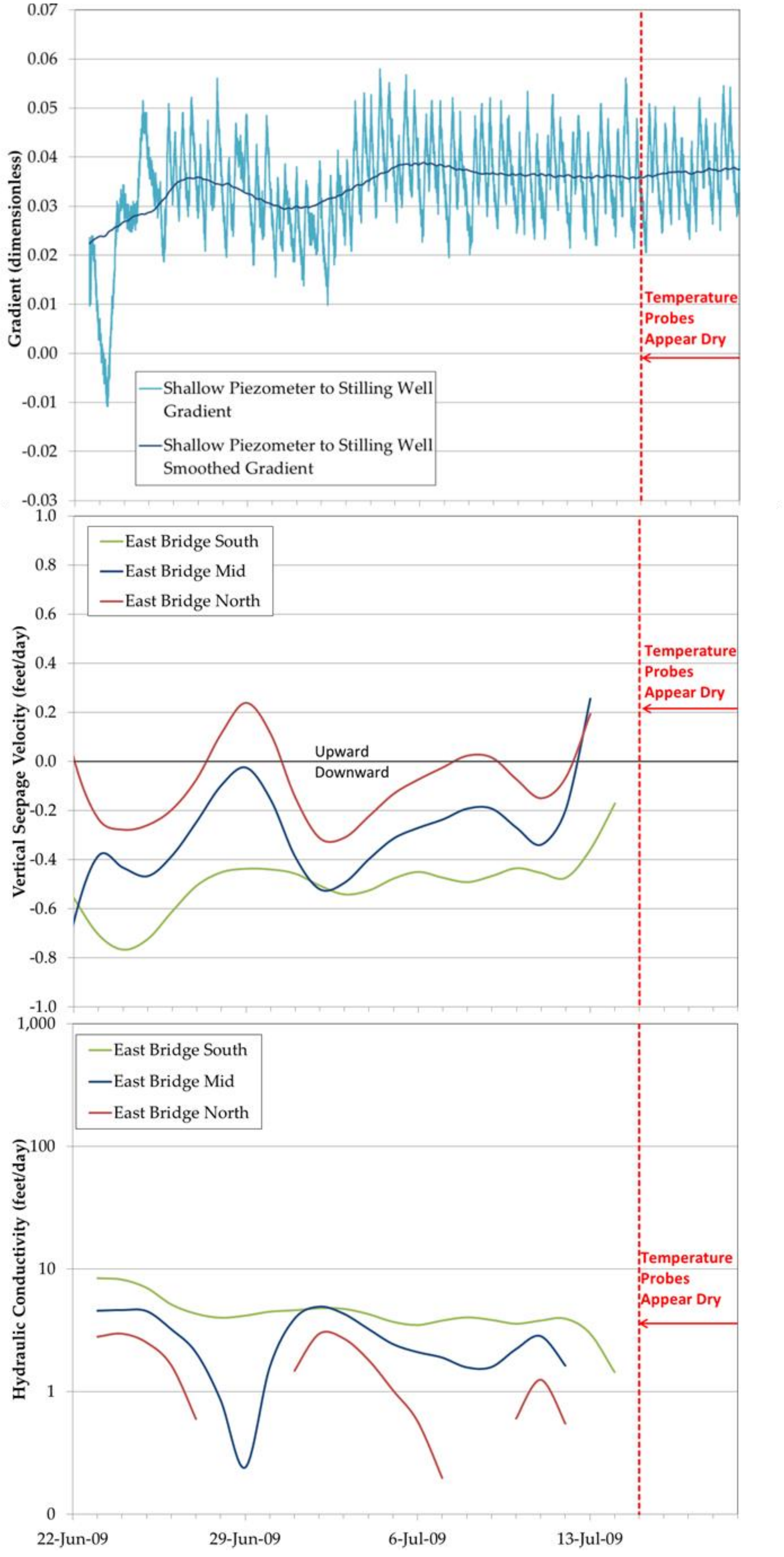

Figure 15: Village East Bridge Gradient, Seepages, and Hydraulic Conductivities

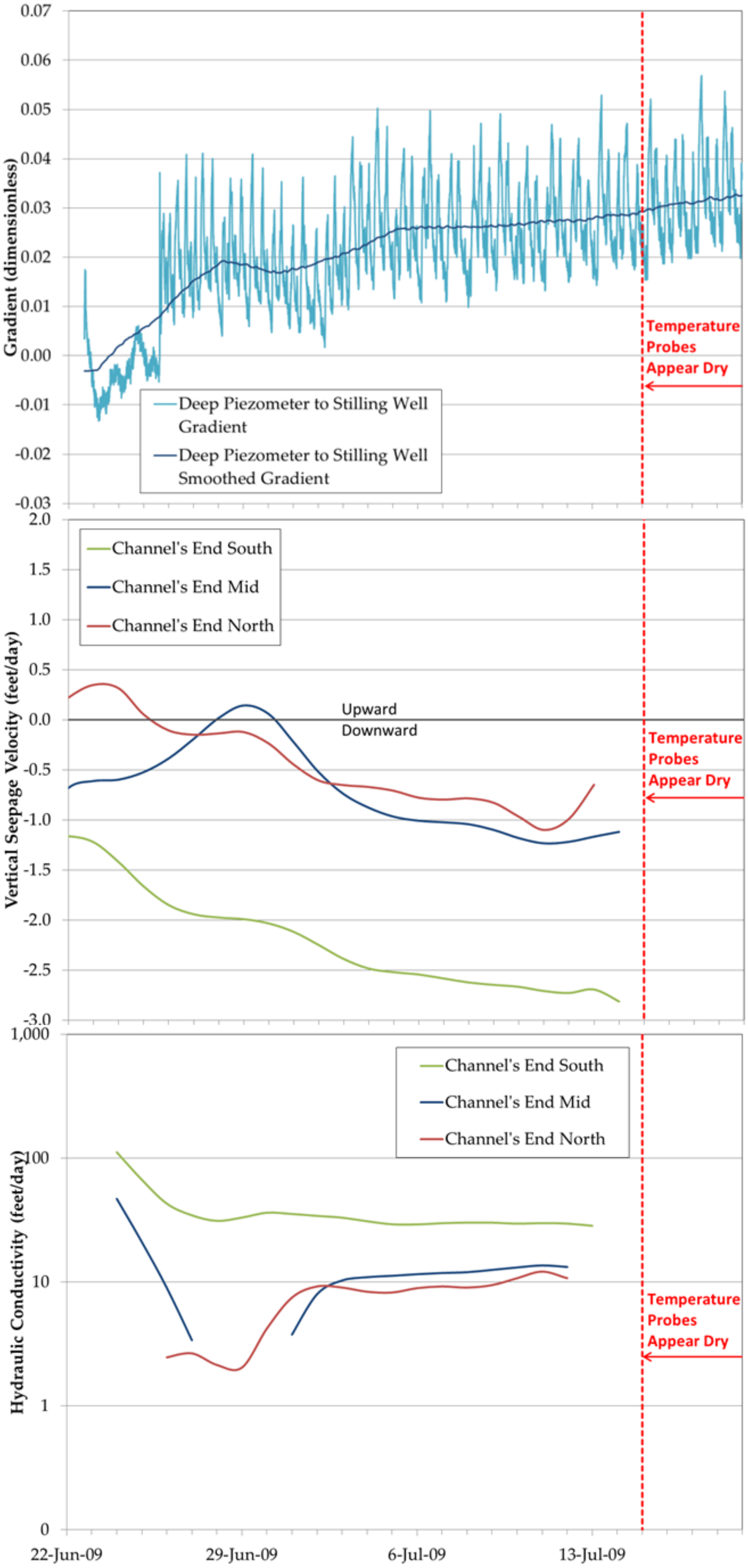

Figure 16: Papoose Bridge Gradient, Seepages, and Hydraulic Conductivities

SECTION 4
CONCLUSIONS

Two sets of temperature probes, shallow piezometers, and stilling wells were installed in Squaw Creek to measure seasonal fluctuations in Creek/Aquifer interactions. All temperature probes recorded informative data sufficient for calculating flows in and out of Squaw Creek for the two time periods of 5/23/2009 to 7/15/2009 and 9/29/2009 to 11/4/2009. A dry period between 7/15/2009 and 9/29/2009 was identified by large fluctuations in temperature recorded by the temperature probes. This dry period does not necessarily correspond to no-flow conditions in Squaw Creek, however the temperature data recorded in this dry period were considered unreliable for calculating Creek/Aquifer interactions.

At the Village East Bridge site, the dominant flow direction was from the aquifer into the Creek. The average amount of water the Creek gains near the Village East Bridge site, for a representative section of the Creek that measures 25 feet by 1,000 feet is 0.02 cfs. At the Papoose Bridge site, the dominant flow direction was from the Creek into the aquifer. The average amount of water the Creek loses near the Papoose Bridge site, for a representative section of the Creek that measures 25 feet by 1,000 feet is 0.09 cfs. The average combined streamflow observed in the Shirley Canyon and South Fork stream gauges was about 13 cfs for the same period. Thus the characteristic seepage rates determined using thermal data are on the order of 0.1 to 0.2% of creek discharge for every 1000 ft. of channel length. Such a small change in discharge cannot be determined using conventional differential-discharge gauging techniques.

Results of streambed seepage calculations revealed spatial and temporal variability in the behavior of the stream-aquifer interaction. Water tended to flow from the aquifer to the Creek during Spring and into early Summer; and from the Creek to the aquifer during mid to late summer when Creek flows are lower and groundwater elevations are below the creek bed. Consistent differences in the magnitude of seepage across the stream's width were observed at both locations. The northern probes showed consistently greater upward and lower downward flows than the other probes. These probes were located near the center of the channel and were assumed to best represent about 50% of the width at both the Village East Bridge and Papoose Bridge location.

Median vertical conductivities of the streambed were found to be around 3 to 15 feet/day. These median values were calculated from the middle probes, which were closest to the stilling well and piezometers and are thought to provide the most self-consistent data. An aquifer test performed on nearby well SVPSD-4R yielded horizontal hydraulic conductivity estimate of about 250 feet/day (HydroMetrics Water Resources Inc., 2013). The ratio of the aquifer horizontal conductivity to the streambed vertical conductivity is therefore between 1:15 and 1:85.

The data collected and analyzed in this study suggest complex Creek/Aquifer interaction. A generalized picture of the Creek/Aquifer interaction occurring during spring and early summer near the Village East Bridge site are shown on Figure 17. Key components of this Creek/Aquifer interaction include:

- Mountain-front recharge raises groundwater elevations north of Squaw Creek above the Creek bed.
- The groundwater north of Squaw Creek discharges into Squaw Creek, increasing Squaw Creek flows.
- Near the middle of Squaw Creek, water begins to discharge from Squaw Creek into the aquifer. The amount of discharge is less than the recharge from the north side of Squaw Creek.
- Discharge from Squaw Creek does not recharge the deeper aquifer immediately below Squaw Creek. Groundwater elevations measured in the deep piezometer suggest that mountain front recharge, and possibly other sources such as deep fracture recharge, are the sources of deep aquifer recharge.

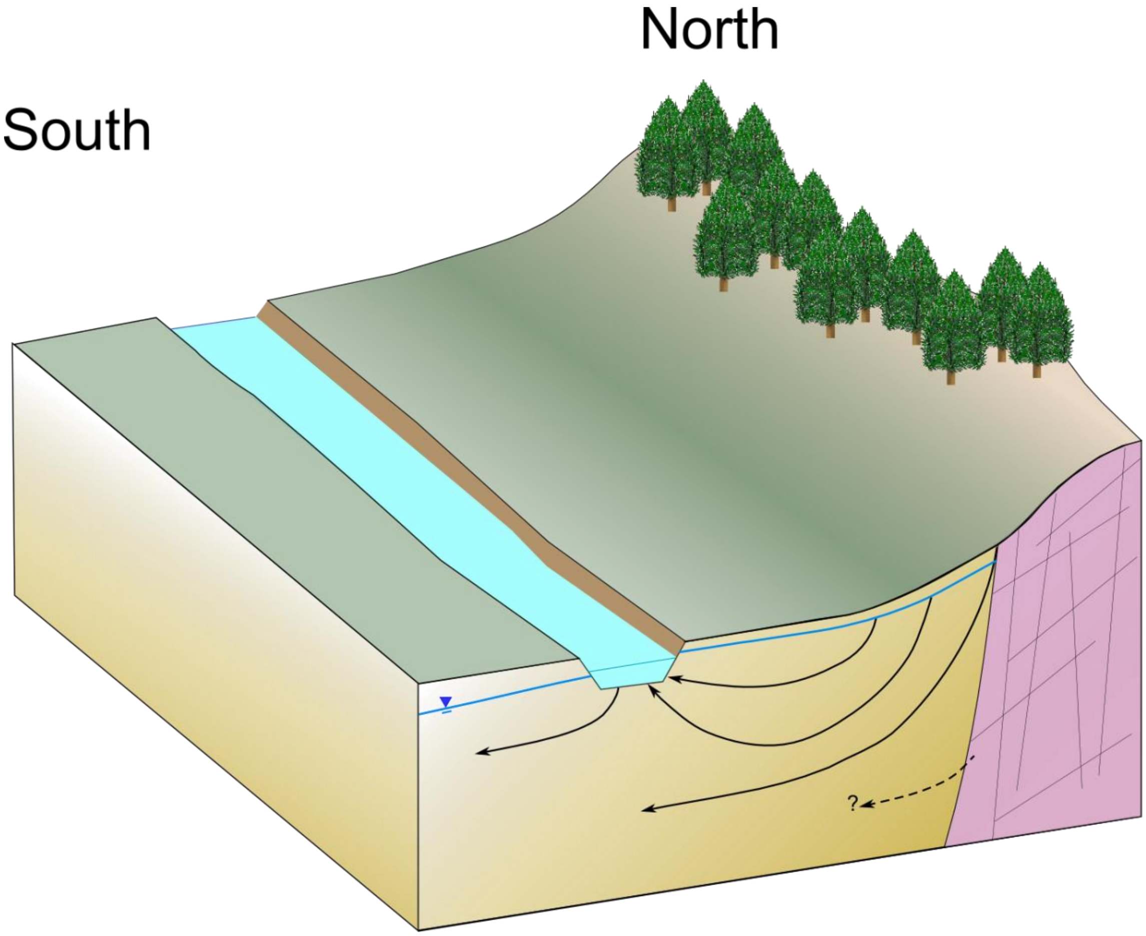

Figure 17: Conceptual Diagram of Stream/Aquifer Interaction during Late Spring and Early Summer

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SECTION 5
REFERENCES

Hatch, C.E., A.T. Fisher, J.S. Revenaugh, J. Constantz, and C. Ruehl, 2005, *Quantifying Surface Water – Ground Water Interactions Using Time Series Analysis of Streambed Thermal Records: Method Development*, *Water. Resour. Res.,* 42(10): 10.1029/2005WR004787.

HydroMetrics WRI, 2013. *Task 4.2 Technical memorandum on pumping impacts on Squaw Creek*. April.

McWhorter, D.B., and D.K. Sunada 1977, *Ground-Water hydrology and hydraulics*. Water Resources Publications, Colorado.

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APPENDIX A: INSTRUMENTATION PHOTOGRAPHS

Figure A-1: Temperature Probe Installation

Figure A-2: Temperature Probe Installation

Figure A-3: Papoose Bridge Temperature Probes, From Bridge

Figure A-4: Village East Bridge Temperature Probes

Figure A-5: Papoose Bridge Temperature Probes

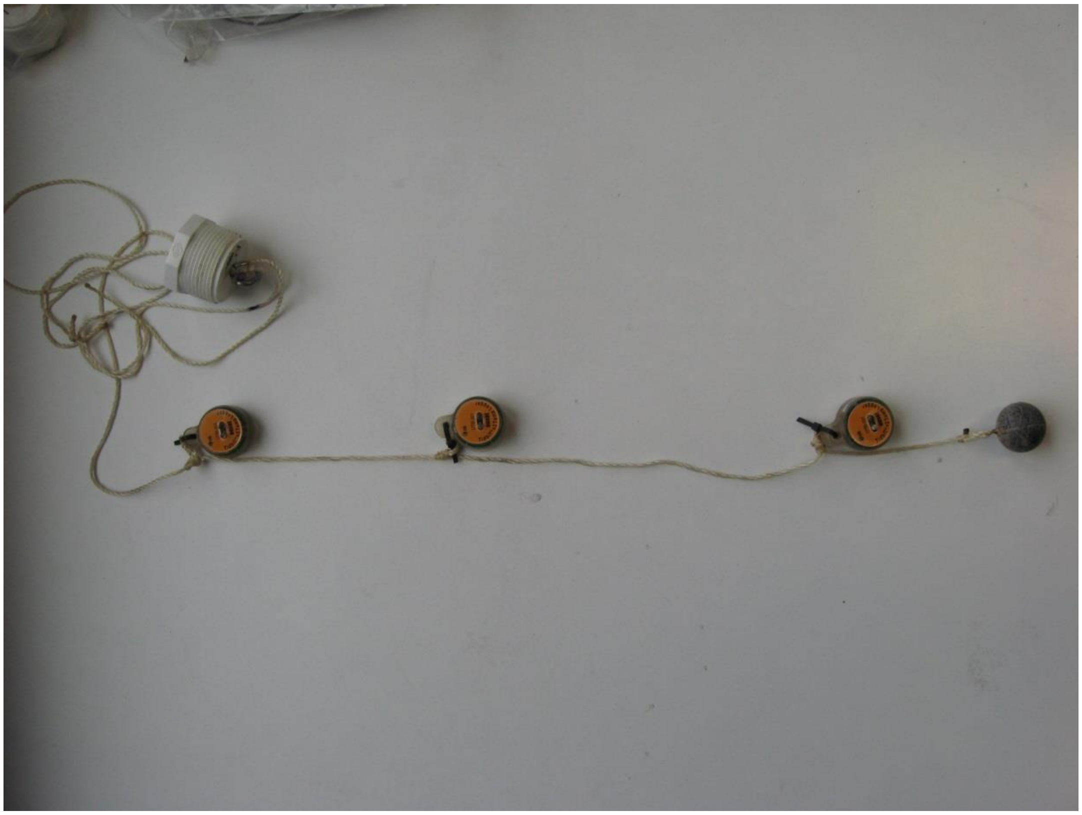

Figure A-6: Temperature Sensors

Figure A-7: Data Retrieval Device

Figure A-8: Micro-Diver® Pressure Transducer

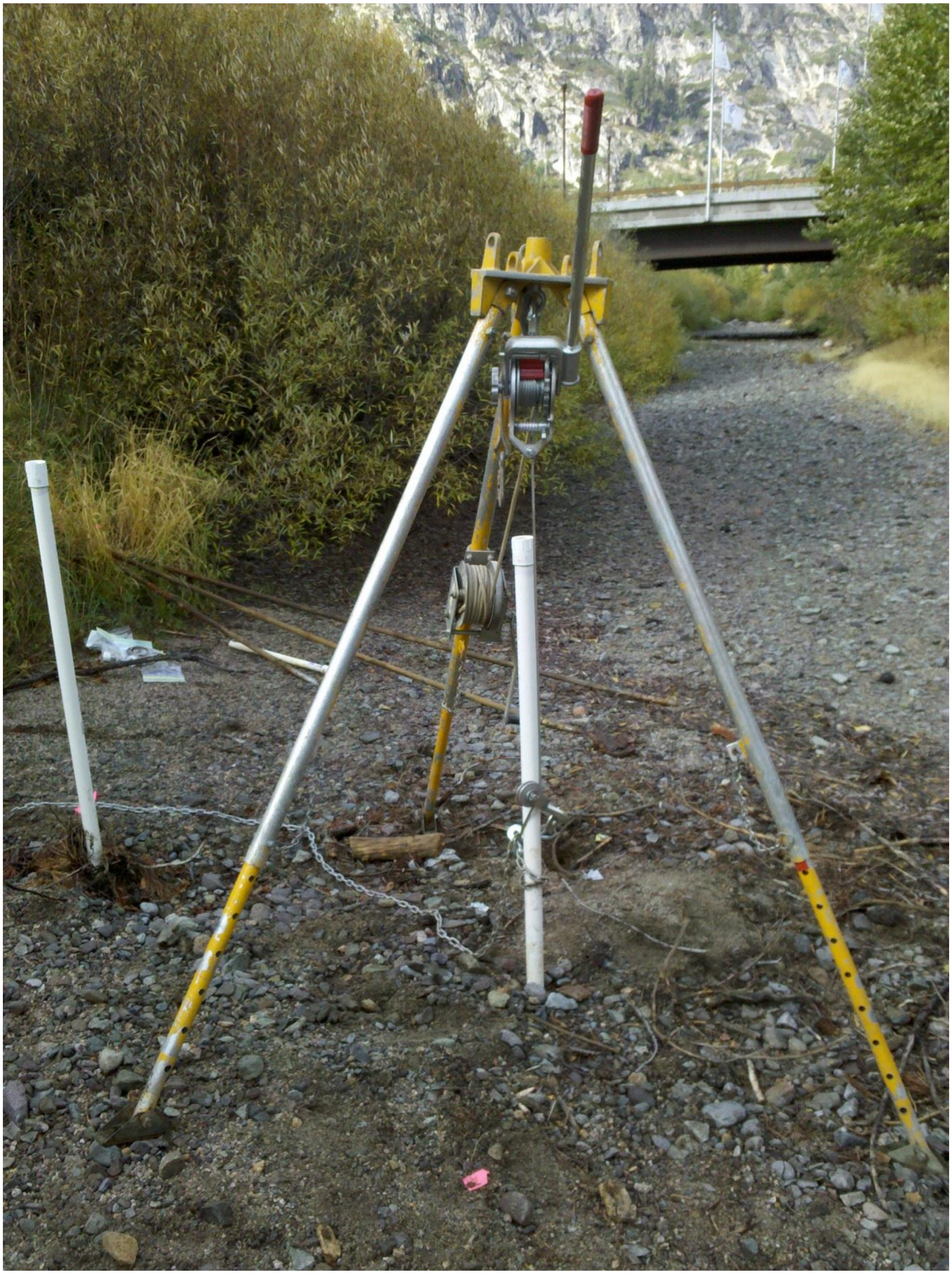

Figure A-9: Removal of Temperature Probe

Figure A-10: Removal of Piezometer

APPENDIX B: SURVEY DATA

ANDREGG GEOMATICS

11661 Blocker Drive, Suite 200, Auburn, CA 95603
Phone (530) 885-7072 | Fax (530) 885-5798
www.andregg.com

LETTER OF TRANSMITTAL

DATE: April 29, 2013	ANDREGG PROJECT#: 13622-01
ATTENTION: Georgina King, PM	CLIENT JOB#:
PHONE #:	FAX #:
RE: Squaw Creek Monitoring Wells	
TOTAL NO. OF PAGES: (incl. Cover)	ANDREGG EMAIL: pcompton@andregg.com

TO

Georgina King, PM
Hydro Metrics Water Resources
519 17th Street, #500
Oakland, CA 94612

WE ARE SENDING YOU ☐ Attached ☐ Under separate cover via

COPIES	DATE	UNIT	DESCRIPTION
1			Squaw Creek Monitoring Wells

REMARKS:

THESE ARE TRANSMITTED as checked below:

☐ For approval ☐ As requested ☐ For review ☐ Other:

Copy To:

Signed:
Parker Compton

GeoTracker XY

NAD83 - California State Plane Coordinates Zone 2 - US Survey Feet
NGVD29 - Based on BM H-172 (PID KS0274) EL: 6177.99

GLOBAL_ID	FIELD_PT_NAME	FIELD_PT_CLASS	XY_SURVEY_DATE	LATITUDE	LONGTITUDE	NORTHING	EASTING	ELEVATION	XY_METHOD	XY_DATUM	XY_ACC_VAL	XY_SURVEY_ORG	GPS_EQUIP_TYPE
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FIELD_PT_NAME	SITE_NAME
601	MW 5 Deep; PVC Pipe
602	MW 5 Shallow; PVC Pipe
603	Stilling Well near 5D/5S; PVC Pipe
604	Deep Piezometer near 5D/5S; Steel Pipe
605	Poulsen Deep; PVC Pipe
606	Poulsen Deep; Steel Casing
607	Poulsen Shallow; PVC Pipe
608	Poulsen Shallow; Steel Casing
609	SCPSD Well 4R; Sounding Tube
610	Stilling Well east of Bridge; PVC Pipe
611	Shallow Piezometer east of Bridge; Steel Pipe
612	Deep Piezometer east of Bridge; Steel Pipe
613	Bank Piezometer east of Bridge; Steel Pipe
614	PlumpJack Shallow; PVC Pipe
615	PlumpJack Shallow; Steel Grate
616	PlumpJack Deep; Steel Grate
617	PlumpJack Deep; PVC Pipe
618	MW 5 Deep; Steel Grate
619	MW 5 Shallow; Steel Grate

GeoTracker Z

NAD83 - California State Plane Coordinates Zone 2 - US Survey Feet
NGVD29 Based on BM H-172 (PID KS0274) EL: 6177.99

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FIELD_PT_NAME	SITE_NAME
601	MW 5 Deep; PVC Pipe
602	MW 5 Shallow; PVC Pipe
603	Stilling Well near 5D/5S; PVC Pipe
604	Deep Piezometer near 5D/5S; Steel Pipe
605	Poulsen Deep; PVC Pipe
606	Poulsen Deep; Steel Casing
607	Poulsen Shallow; PVC Pipe
608	Poulsen Shallow; Steel Casing
609	SCPSD Well 4R; Sounding Tube
610	Stilling Well east of Bridge; PVC Pipe
611	Shallow Piezometer east of Bridge; Steel Pipe
612	Deep Piezometer east of Bridge; Steel Pipe
613	Bank Piezometer east of Bridge; Steel Pipe
614	PlumpJack Shallow; PVC Pipe
615	PlumpJack Shallow; Steel Grate
616	PlumpJack Deep; Steel Grate
617	PlumpJack Deep; PVC Pipe
618	MW 5 Deep; Steel Grate

GeoTracker Z

NAD83 - California State Plane Coordinates Zone 2 - US Survey Feet
NGVD29 Based on BM H-172 (PID KS0274) EL: 6177.99

619	MW 5 Shallow; Steel Grate

APPENDIX C: STREAMBED TEMPERATURE DATA

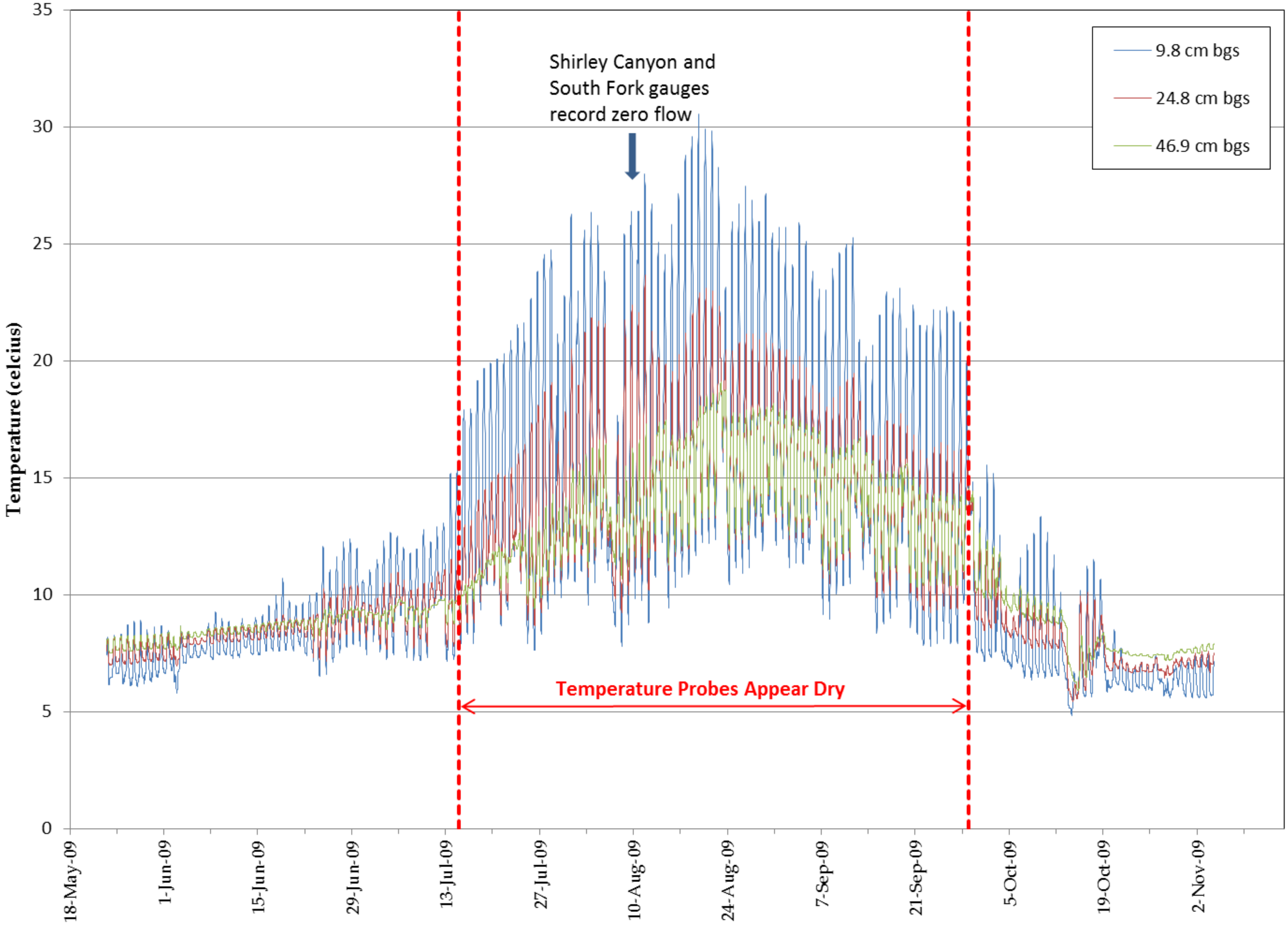

Figure C-1: Village East Bridge South Temperature Probe

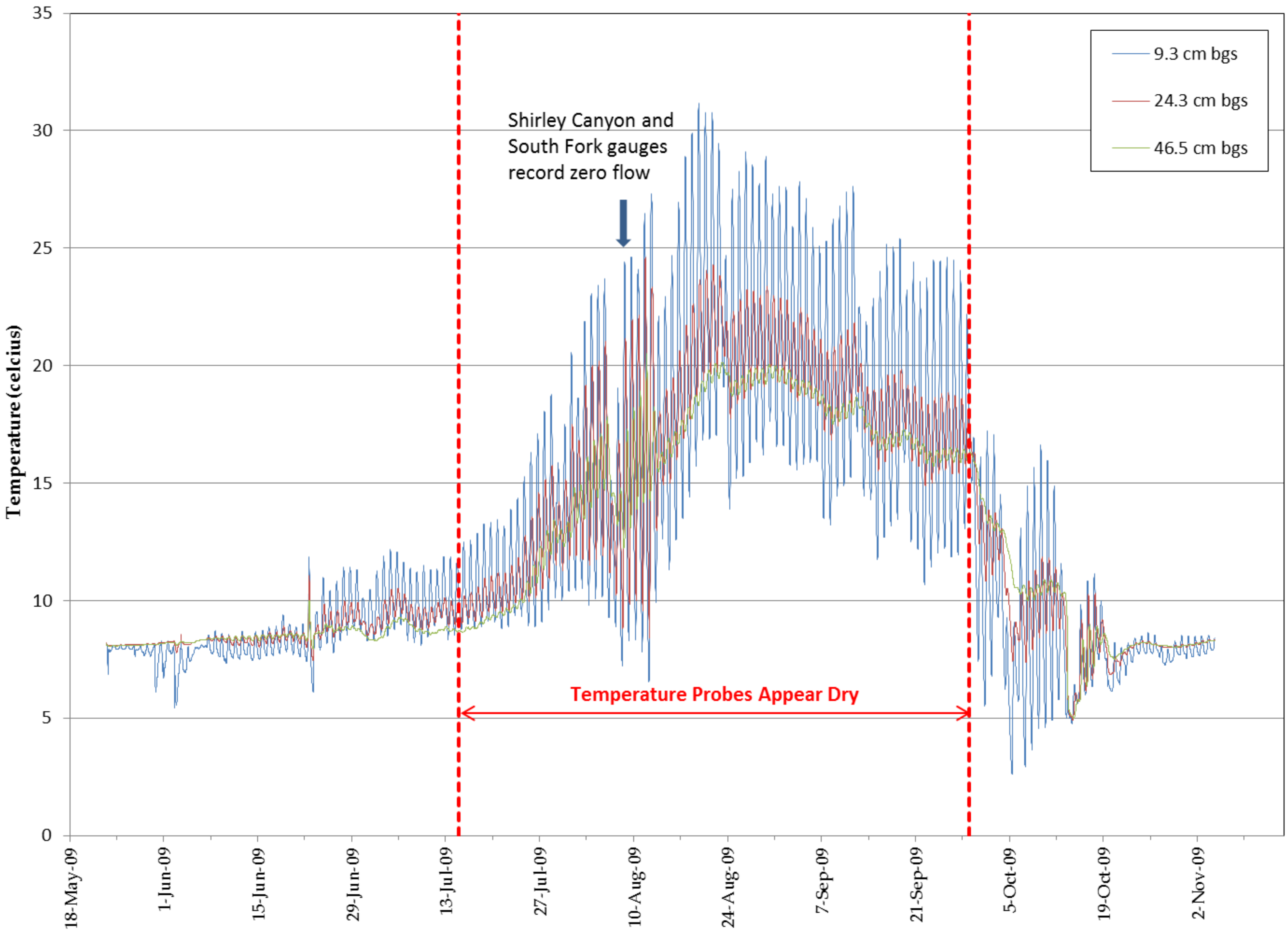

Figure C-2: Village East Bridge Middle Temperature Probe

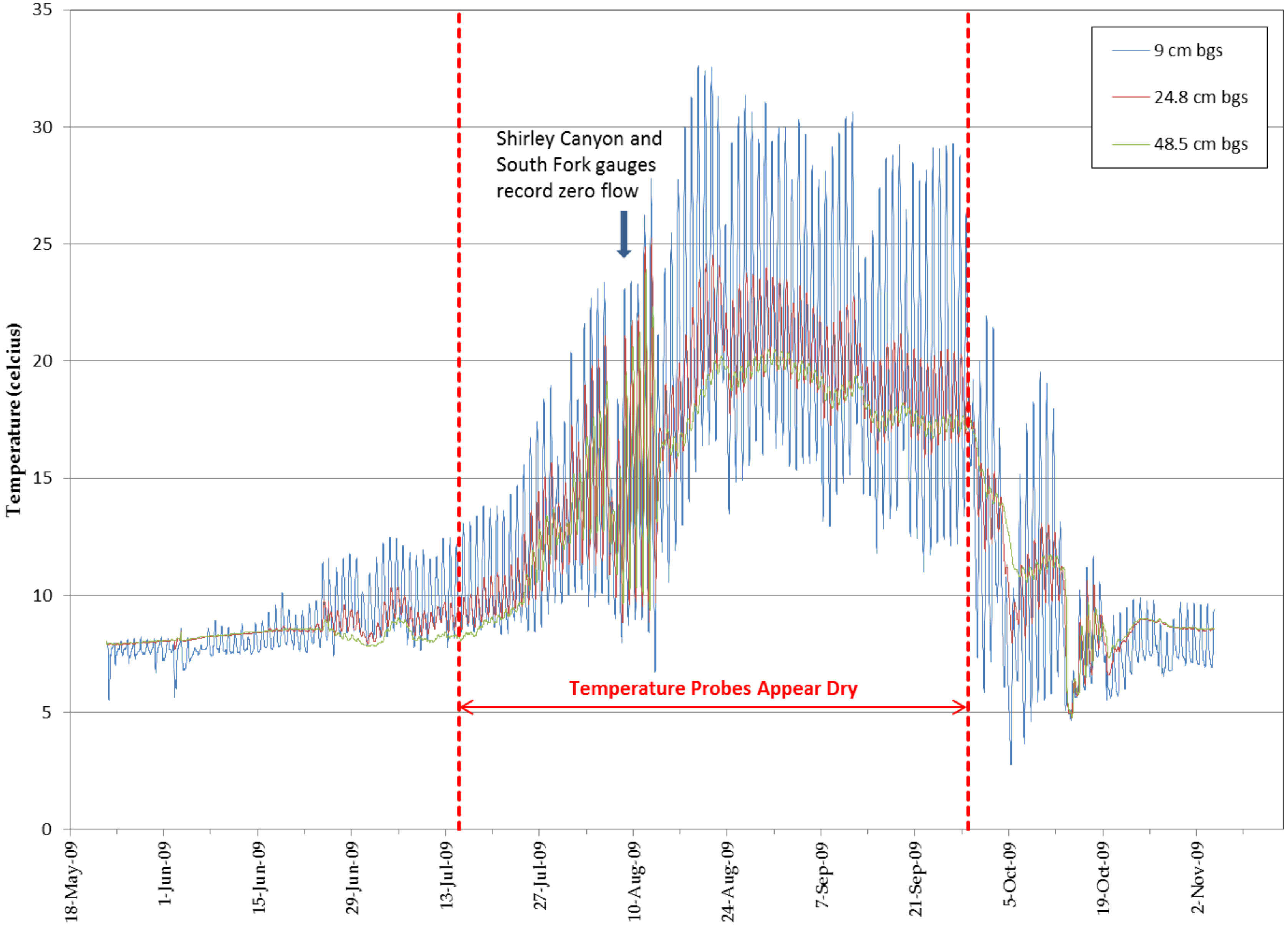

Figure C-3: Village East Bridge North Temperature Probe

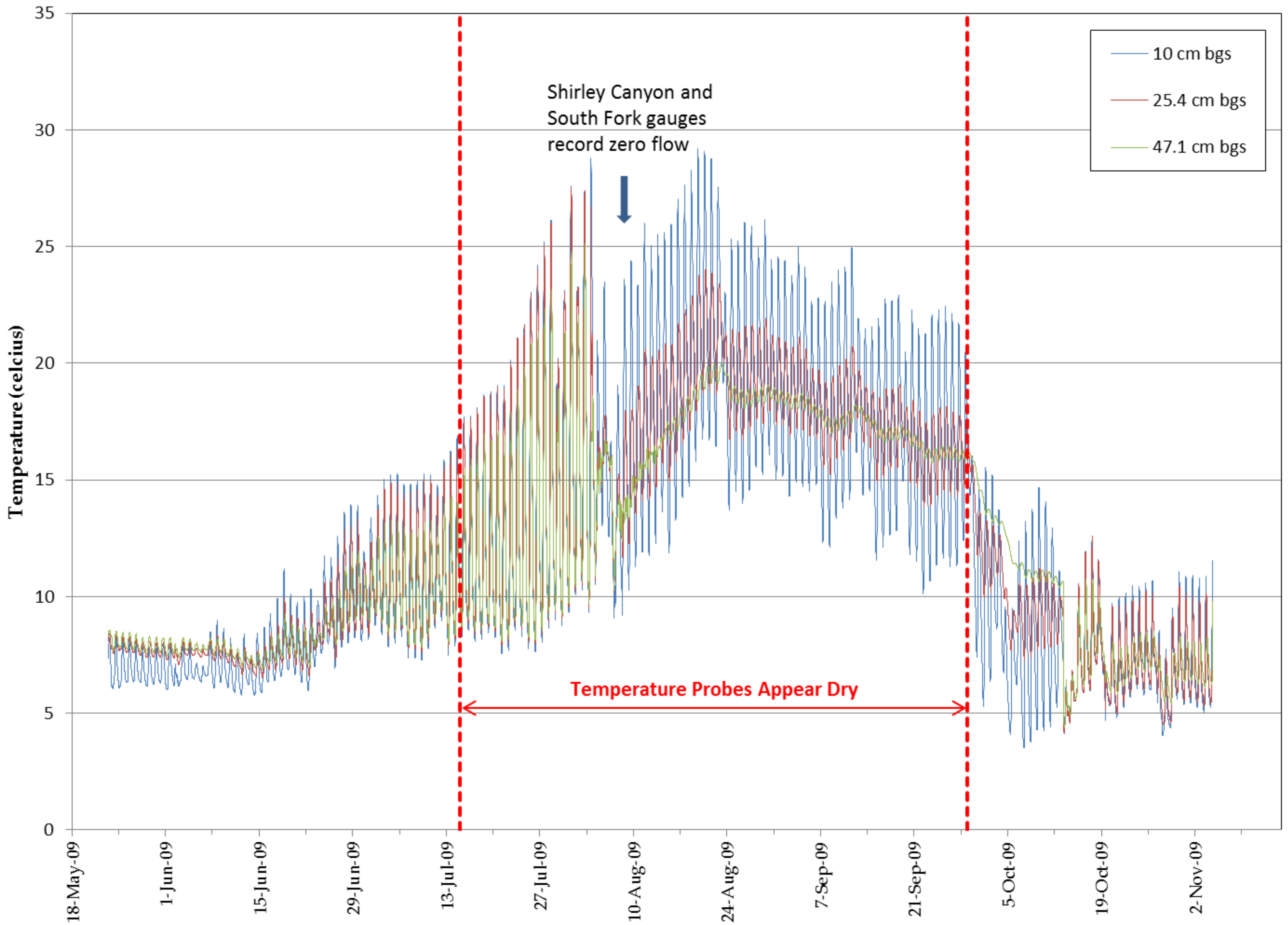

Figure C-4: Papoose Bridge South Temperature Probe

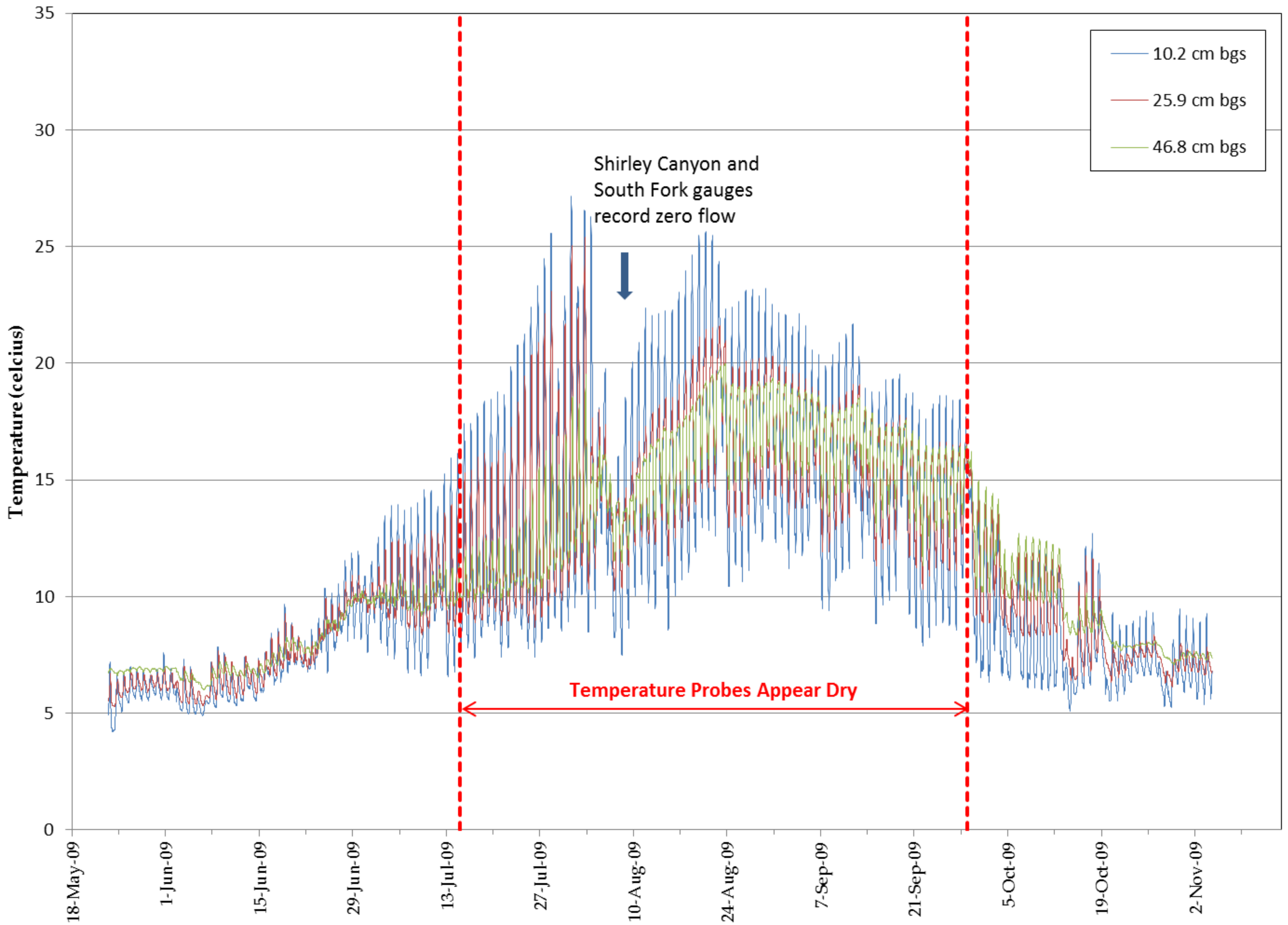

Figure C-5: Papoose Bridge Middle Temperature Probe

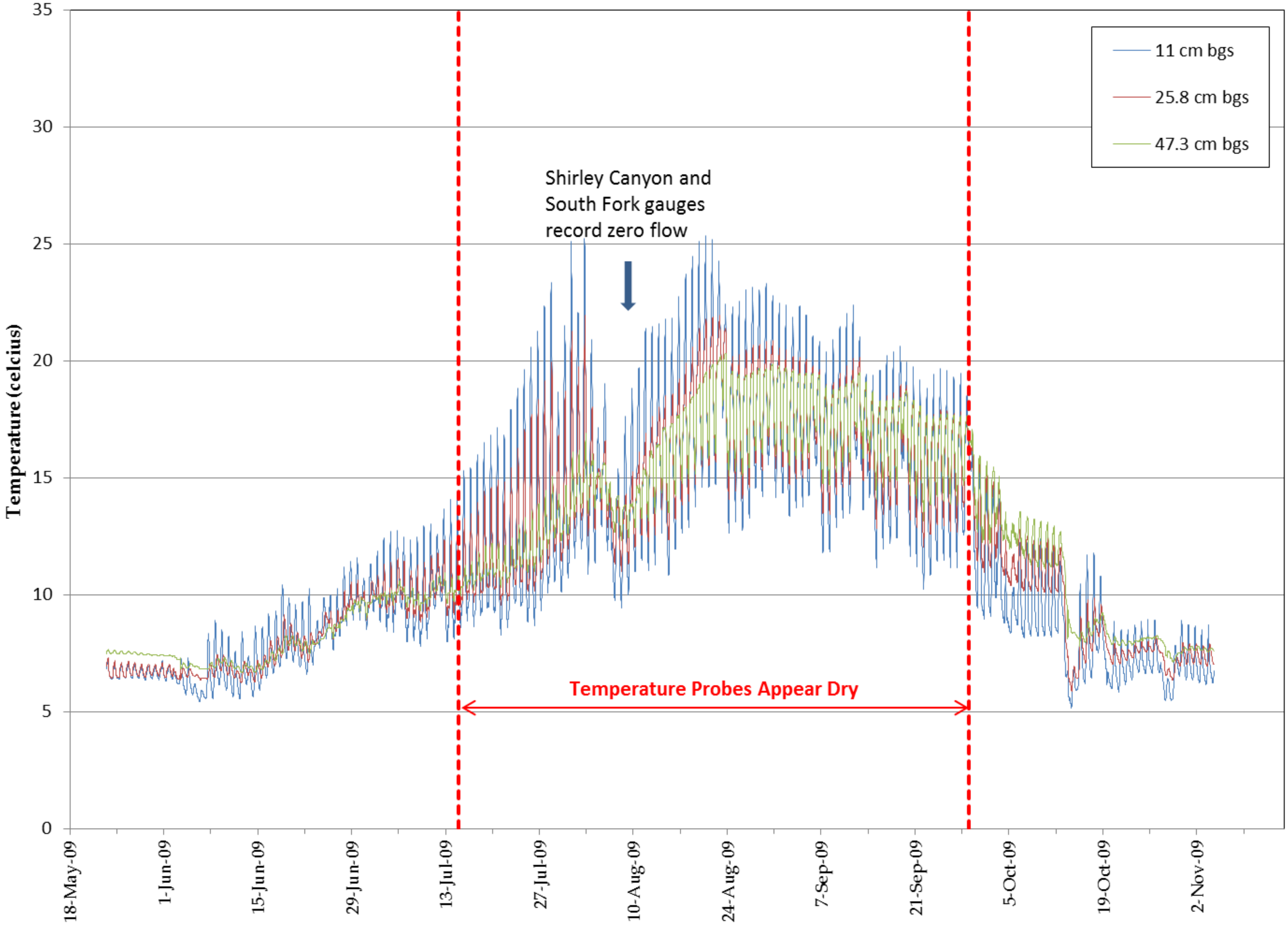

Figure C-6: Papoose Bridge North Temperature Probe

Task 4.2
Technical Memorandum on Pumping Impacts on Squaw Creek


Aquifer Test 1


Aquifer Test 2

Prepared for:
Squaw Valley Public Service District
April 2013

Prepared by:
HydroMetrics WRI

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Appendix A: Drawdown Results

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ABBREVIATIONS

cfs	cubic feet per second
gpm	gallons per minute
SVPSD	Squaw Valley Public Service District

SECTION 1
BACKGROUND AND PURPOSE

The Squaw Valley Creek/Aquifer Interaction Project was initiated in response to the State Water Resources Control Board's Resolution No. 2007-0008, which resolved to direct the Lahontan Water Board to continue supporting the efforts of entities pumping groundwater as well as other stakeholders in Squaw Valley to: (1) minimize effects on the creek, (2) develop a groundwater management plan that recognizes potential effects of pumping on the creek and seeks to minimize or eliminate adverse effects on Squaw Creek, and (3) conduct a study of potential interaction between groundwater pumping and flows in Squaw Creek.

Limited water supplies in Olympic Valley have resulted in a perceived competition between water needed for municipal and irrigation supplies, and water needed for environmental sustainability. Additionally, the channelization of Squaw Creek in the late 1950s by the Army Corp of Engineers improved drainage, but resulted in the unintended consequence of draining shallow groundwater away from the aquifer. This resulted in two problems; first the trapezoidal channel quickly depletes the available water for in-stream flows much earlier in the season than a natural creek bed would, and secondly the channel drains water away from the well field reducing the available water in the aquifer for water supply.

The Squaw Valley Creek/Aquifer Interaction Project's overall goals are:

1. Improve and quantify our understanding of creek/aquifer interaction;
2. Diminish groundwater pumping impacts on Squaw Creek; and
3. Increase groundwater storage in Olympic Valley.

A key part of the Squaw Valley Creek/Aquifer Interaction program was conducting and analyzing two aquifer tests. One aquifer test was conducted while Squaw Creek was flowing; and one aquifer test was conducted while Squaw Creek was dry. Comparing results from these two tests allows us to identify the influence from Squaw Creek on well pumping, and to quantify the amount of water that is captured by the pumping well from Squaw Creek. This memorandum presents the methodology, analyses results, and conclusions from the two aquifer tests.

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SECTION 2
METHODOLOGY

Two nearly-identical aquifer tests were performed at different times by pumping Squaw Valley Public Services District (SVPSD) production well SVPSD#2 in Squaw Valley. The only significant difference between the two aquifer tests is that Squaw Creek was flowing during the first, and was dry during the second test. All reasonable efforts were made to conduct the two tests in identical fashions.

Groundwater levels were recorded in the pumping well, six monitoring wells, and four temporary piezometers during both tests. The locations of the pumping well, monitoring wells, and piezometers are shown in Figure 1. The names of all the groundwater level monitoring locations, depths of all monitoring locations, and distance of each groundwater level monitoring location from pumping well SVPSD#2 are shown in Table 1.

Table 1: Monitoring Locations and Depths

Groundwater Level Monitoring Location	Screen Depth (feet)	Distance from Pumping Well SVPSD#2 (feet)
Well SVPSD#2	33 - 74	N/A
Well SVPSD-4R	40 - 70	171
Well MW-5S	10 - 20	587
Well MW-5D	80 - 90	587
Well SVMWC#1	60 - 60	535
Poulsen Shallow Monitor Well	9 - 29	945
Poulsen Deep Monitor Well	85 - 105	945
Village East Bridge Bank Piezometer	8.2 - 8.7	381
Village East Bridge Shallow Piezometer	4.8 - 5.3	391
Village East Bridge Deep Piezometer	9.7 - 10.2	391
Papoose Bridge Deep Piezometer	9.9 - 10.4	608

Figure 1: Aquifer Test Groundwater Level Monitoring Locations

During both tests, groundwater level data were collected with Schlumberger Micro-Diver pressure transducers and data loggers at constant five minute intervals. Hand measured groundwater levels were collected at all monitoring wells as backup to the data loggers. Well SVMWC#1 had no data logger and therefore only hand-measured groundwater level data were collected. Discharge from well SVPSD#2 was recorded by SVPSD's SCADA system during both tests.

To isolate the impact of flows in Squaw Creek on nearby groundwater levels, identical procedures were followed during both aquifer tests. Test-specific information and procedures are mentioned in the individual sections below.

Groundwater levels were allowed to recover prior to both tests by ceasing the operation of wells in the immediate vicinity of well SVPSD#2 for at least 24 hours prior to pumping. To maintain water supply to Squaw Valley residents, well SVMWC#2 (Figure 1) could not remain inactive during the tests, and the rates and timing of this well's production are unknown.

2.1 AQUIFER TEST 1

Aquifer Test 1 began on June 23, 2009 while Squaw Creek was flowing (Figure 2). Details of the test are shown in Table 2.

Table 2: Aquifer Test 1 Details

Start Time	6/23/2009 8:20 AM
End Time	6/25/2009 11:20 AM
Total Pumping Time	51 hours
Time that Wells Were Rested Prior to Pumping	> 24 hours
Amount of Recovery Data Collected	2.5 hours
Flow condition in Squaw Creek	Flowing
Average Pumping Rate	316 gpm

During Aquifer Test 1, water levels were collected from stilling wells installed in Squaw Creek. Two stilling wells were measured, one at the Village East Bridge set of piezometers and one at the Chanel's End piezometer.

2.2 AQUIFER TEST 2

Aquifer Test 2 began on September 8, 2010 while Squaw Creek was dry (Figure 3). Details of the test are shown in Table 3.

Table 3: Aquifer Test 2 Details

Start Time	9/8/2010 8:40 AM
End Time	9/10/2010 11:40 AM
Total Pumping Time	51 hours
Time that Wells Were Rested Prior to Pumping	> 24 hours
Amount of Recovery Data Collected	2.5 hours
Flow condition in Squaw Creek	Dry
Average Pumping Rate	308 gpm

Figure 2: Squaw Creek Flowing Past Shallow Piezometer (Foreground) During Aquifer Test 1

Figure 3: Dry Squaw Creek and Piezometers During Aquifer Test 2

SECTION 3
RESULTS AND ANALYSIS

3.1 DRAWDOWN RESULTS

Drawdowns were calculated for each monitoring location by subtracting groundwater elevations measured during the test from the pre-test groundwater elevation. The consistency and degree of the drawdown observed during pumping varied by location and by test. The drawdowns observed at each monitoring location are plotted and discussed in Appendix A. Each plot in Appendix A shows measured drawdown for both tests at a single location. Where appropriate, measured stream level fluctuations are also shown on the figures. These plots were analyzed to determine the degree of influence aquifer test pumping, Squaw Creek flows, and other background pumping had on measured groundwater levels. Any monitoring location that showed reasonable drawdown from the test pumping was included in the aquifer test analysis. The full explanation of which locations provided reasonable data from each test is included in Appendix A.

3.2 AQUIFER PARAMETER ESTIMATION

Based on the drawdown plots shown in Appendix A, a number of monitoring locations for each test were selected for estimating aquifer parameters. Aquifer parameters were estimated using the Aquifer^{Win32} software package (ESI, 2003). Transmissivity and storage coefficients were estimated using the Theis solution (Theis, 1935).

3.2.1 AQUIFER PARAMETERS ESTIMATED FROM AQUIFER TEST 1

Drawdown data from well SVPSD-4R and well MW-5D were used to estimate aquifer parameters from Aquifer Test 1. These two monitoring locations showed ample pumping induced drawdown that was not overwhelmed by influences from Creek flow fluctuations. The full justification for using these two monitoring locations rather than other monitoring locations in the analysis of Aquifer Test 1 is presented in Appendix A.

Drawdown data from each well were adjusted by their radial distance from pumping well SVPSD#2, plotted together, and compared to the Theis curve. Under ideal conditions the data from each monitoring location would align together in the shape of a characteristic Theis curve. From this curve a single set of transmissivity and storage coefficient values would be estimated. For test 1, the data from wells SVPSD-4R and MW-5D did not form a single drawdown curve when plotted with the Theis curve. Therefore, two sets of aquifer parameters were estimated: one set for each monitoring location. There may be a number of reasons why data from well SVPSD-4R and MW-5D did not form a single drawdown curve. Aquifer heterogeneity may result in different aquifer parameters at the two monitoring wells. Optionally, the presence of the flowing Squaw Creek in close proximity to well MW-5D is a significant divergence from the Theis solution assumptions, and may cause a lack of alignment of the drawdown curves.

Results of the two curve matching exercises are displayed in Figure 4 and Figure 5. The aquifer parameters derived from the Theis curve matching exercise are summarized in Table 4. The hydraulic conductivity value shown in Table 4 assumes an aquifer thickness of 74 feet: the depth of well SVPSD#2. These calculations may overestimate the hydraulic conductivity by underestimating the aquifer thickness. A number of other wells in the area including wells SVPSD#1, SVPSD#3, SVPSD#5R, SVMWC#1, and SVMWC#2 are over 100 feet deep. Using the thicker aquifer values observed in these wells would result in lower hydraulic conductivities.

Table 4: Aquifer Test 1 Parameter Estimates

Well	Transmissivity (ft^2/day)	Hydraulic Conductivity (ft/day)	Storage Coefficient
SVPSD-4R	38,147	515	0.006
Village East Bridge Bank Piezometer	55,911	755	0.048

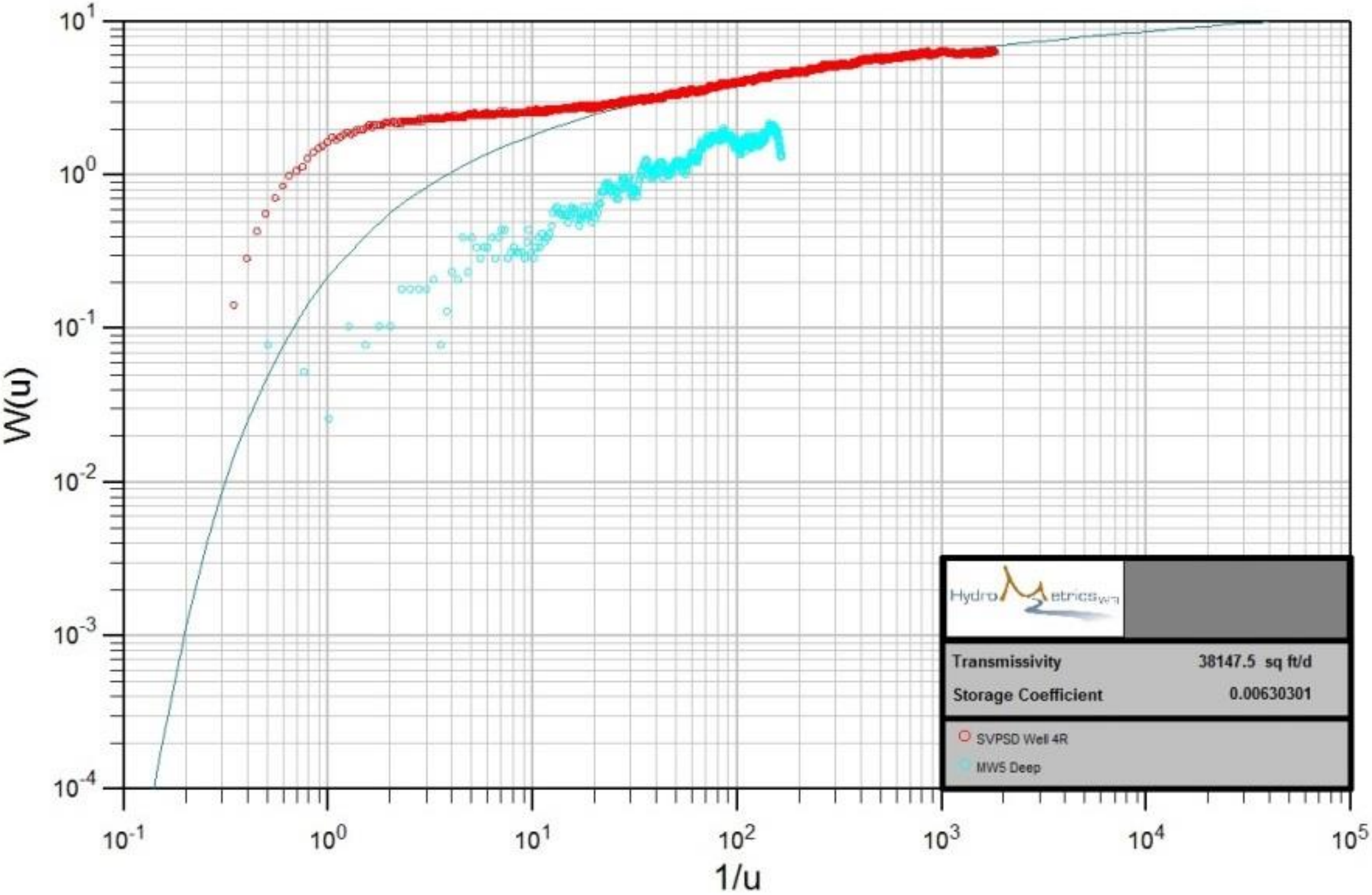

Figure 4: Aquifer Test 1 Theis Solution Matched to Well SVPSD-4R

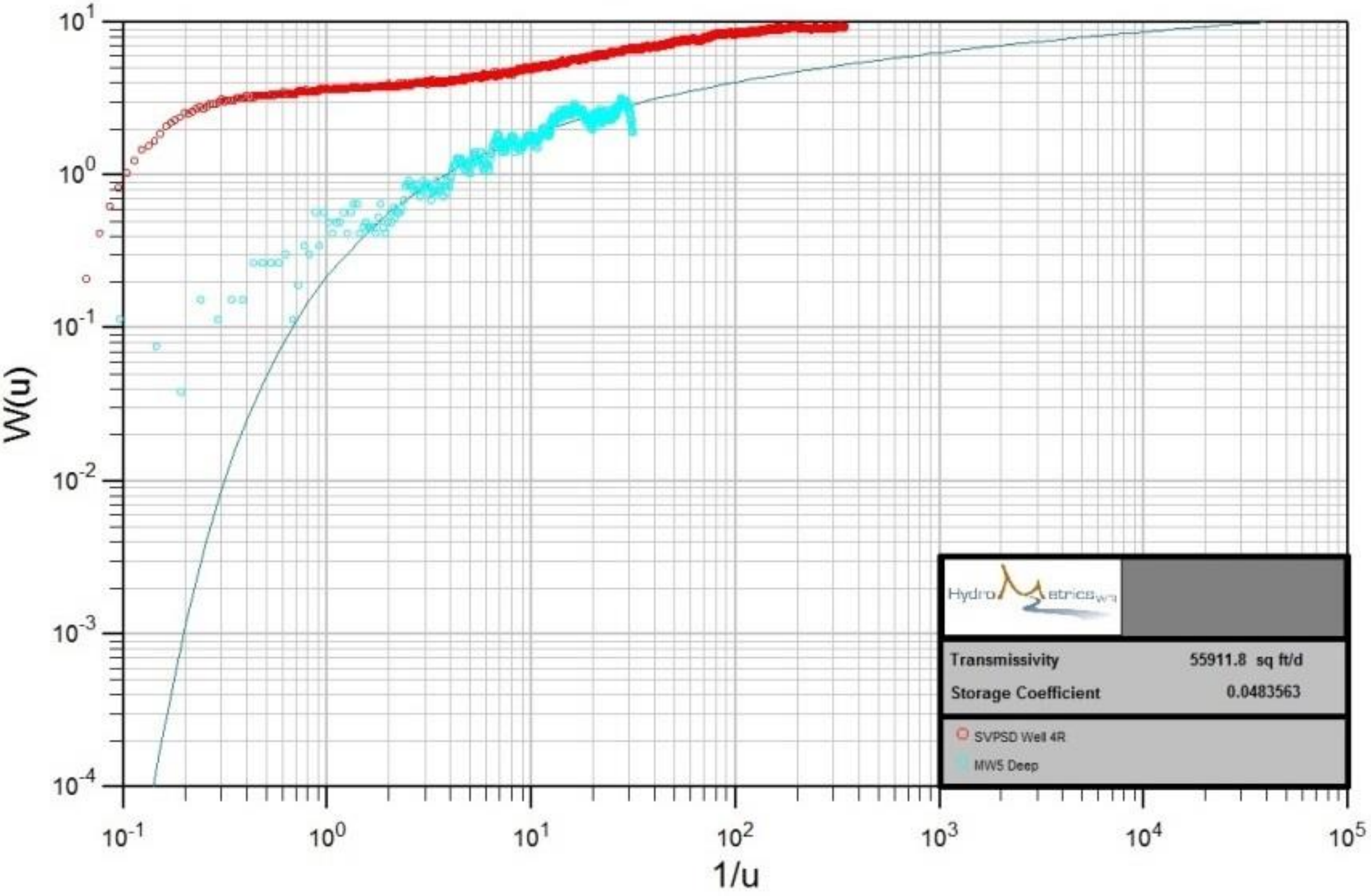

Figure 5: Aquifer Test 1 Theis Solution Matched to Well MW-5D

3.2.2 AQUIFER PARAMETERS ESTIMATED FROM AQUIFER TEST 2

Drawdown data from four monitoring locations were used to estimate aquifer parameters from Aquifer Test 2. The four monitoring locations used for analysis included:

- Well SVPSD-4R
- Well MW-5D
- Village East Bridge Shallow Piezometer
- Village East Bridge Deep Piezometer

These four monitoring locations showed ample pumping induced drawdown. The full justification for using these four monitoring locations rather than other monitoring locations in the analysis of Aquifer Test 2 is presented in Appendix A.

Drawdown data from each well were adjusted by their radial distance from pumping well SVPSD#2, plotted together, and compared to the Theis curve. Under ideal conditions the data from each monitoring location would align together in the shape of a characteristic Theis curve. From this curve a single set of transmissivity and storage coefficient values would be estimated. For Aquifer Test 2, the data from well SVPAD-4R did not align with the data from the other three monitoring locations. Therefore, two sets of aquifer parameters were estimated: one set for well SVPSD-4R and one set for the remaining three monitoring locations.

Results of the two curve matching exercises are displayed in Figure 6 and Figure 7. The aquifer parameters derived from the Theis curve matching exercise are summarized in Table 5. The hydraulic conductivity value shown in Table 5 assumes an aquifer thickness of 74 feet: the depth of well SVPSD#2. These calculations may overestimate the hydraulic conductivity by underestimating the aquifer thickness. A number of other wells in the area including wells SVPSD#1, SVPSD#3, SVPSD#5R, SVMWC#1, and SVMWC#2 are over 100 feet deep. Using the thicker aquifer values observed that these wells would result in lower hydraulic conductivities.

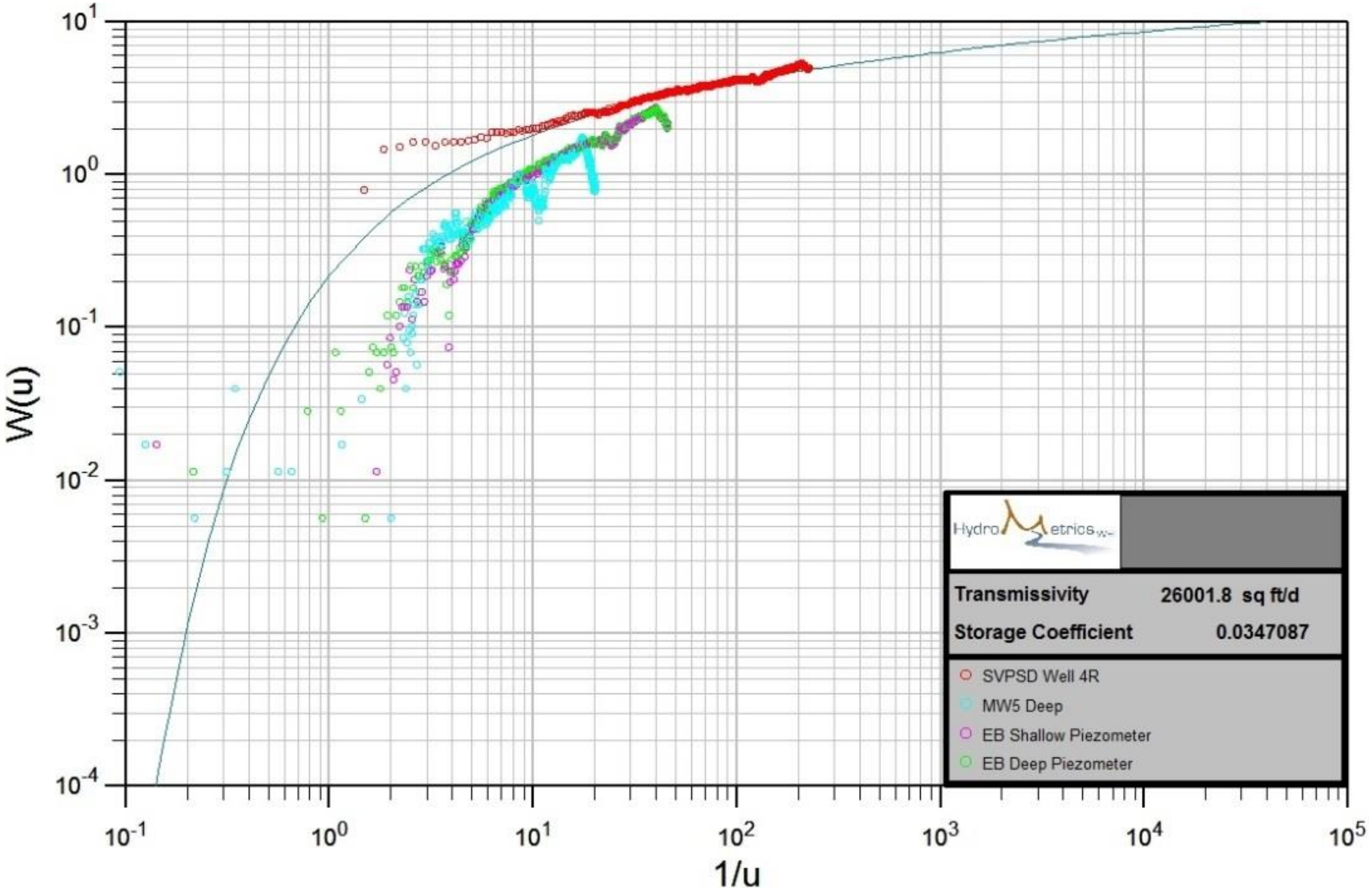

Figure 6: Aquifer Test 2 Theis Solution Matched to Well SVPSD-4R

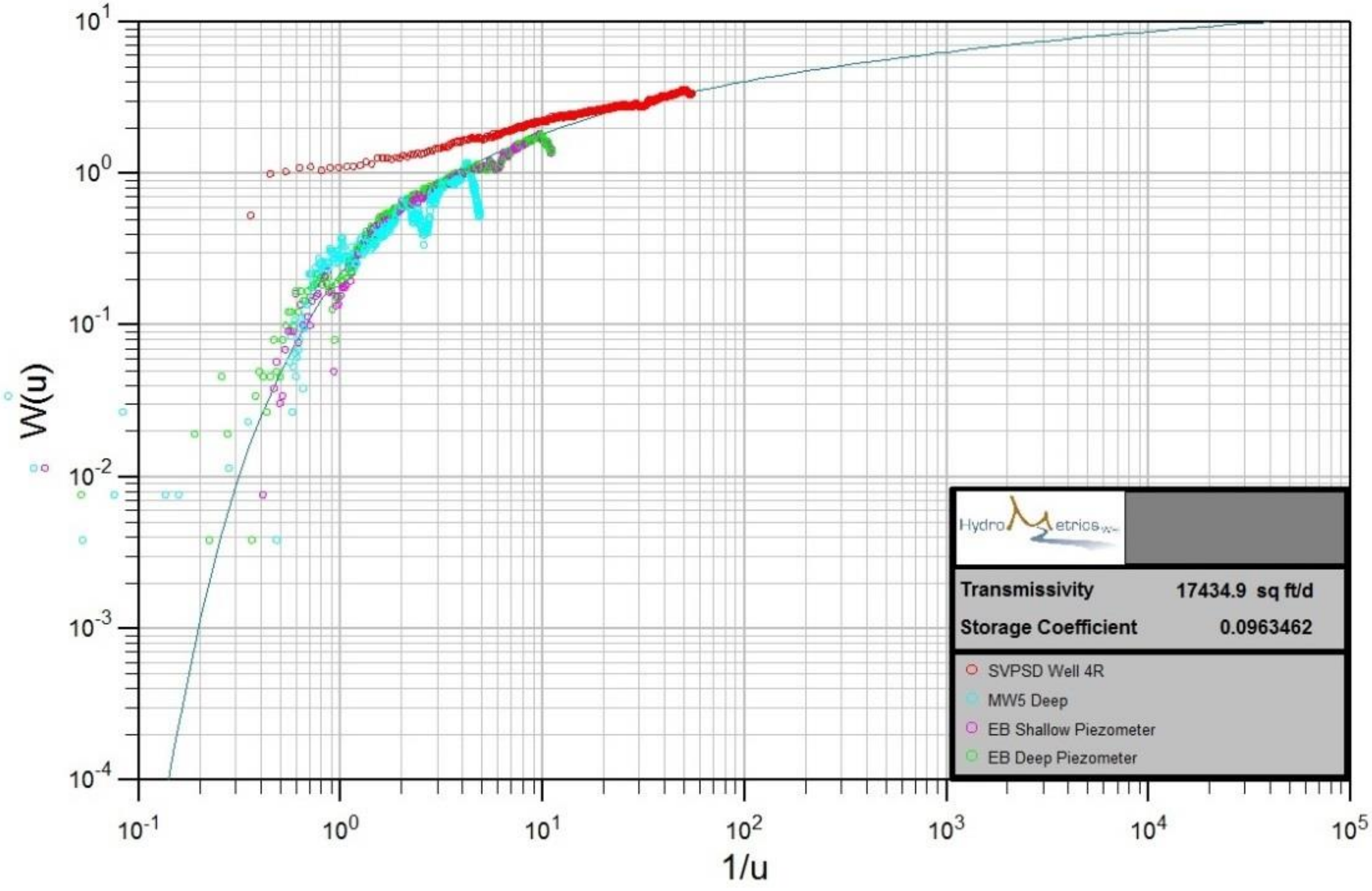

Figure 7: Aquifer Test 2 Theis Solution Matched to Three Distant Monitoring Locations

Table 5: Aquifer Test 2 Parameter Estimates

Well	Transmissivity (ft^2/day)	Hydraulic Conductivity (ft/day)	Storage Coefficient
SVPSD-4R	26,001	351	0.035
Aggregate curve: SVPSD-4R (late data), MW-5D, Village East Bridge Shallow and Deep Piezometers	17,435	235	0.096

3.3 STREAMFLOW DEPLETION FROM PUMPING

Relative drawdowns observed between Aquifer Test 1 when Squaw Creek was flowing, and Aquifer Test 2 when Squaw Creek was dry, suggest that there is a close hydrologic connection between the water in Squaw Creek and the groundwater in the local aquifers. Because of this close hydrologic connection, pumping municipal wells may deplete creek flow by capturing water from the creek. We used an analytical solution to estimate the amount of water that well SVPSD#2 captures from Squaw Creek during spring runoff conditions.

The Hunt solution (Hunt, 1999) predicts the amount of streamflow lost to a nearby well that is pumping at a constant rate. The streamflow loss increases with time and is expressed as a proportion of the pumping rate from the well. The result of this analysis is a streamflow depletion curve that can be used to estimate the effect of pumping on streamflow losses. This curve indicates what proportion of the total water extracted from a well is derived from streamflow loss.

The Hunt equation requires values of aquifer transmissivity and storage coefficient, as well as streambed conductivity, and streambed depth. The transmissivity and storage coefficient values used were those estimated from the results of Aquifer Test 2 using the sets of data from the Village East Bridge Piezometers, well MW-5D, and well SVPSD-4R (Table 5). These parameters were chosen to reflect the properties of the near-stream aquifer materials that are important in the streambed depletion analysis. In addition, the conditions of Aquifer Test 2 are more consistent with the assumptions of the Theis solution and are believed to be more reliable estimates overall.

Streambed conductivity (Kz) and streambed thickness were derived from analysis of temperature data collected between May, 2009 and October 2009 (HydroMetrics Water Resources Inc., 2013). All parameters used in the Hunt (1999) analysis are shown in Table 6.

Table 6: Squaw Creek Capture Analysis Parameters

Parameter	Value
Aquifer transmissivity (T)	17,435 feet^2/day
Storage coefficient (S)	0.096
Streambed conductivity (K_z)	3 feet/day
Streambed thickness (b)	4 feet
Stream width (w)	25 feet
Distance from well to stream (l)	350 feet

Figure 8 shows the streamflow depletion curve that was calculated for well SVPSD#2. Time since pumping began is plotted on the X-axis. The percentage of pumping that is derived from the stream is plotted on the Y-axis. The two sets of red dashed lines on Figure 8 are examples of how to calculate the amount of flow captured from Squaw Creek by well SVPSD#2 during average conditions, and at the end of Aquifer Test 1.

Figure 8 shows that at the end of Aquifer Test 1, after 51 hours of pumping, well SVPSD#2 captured approximately 21.5% of its total discharge from Squaw Creek. Assuming an average pumping rate of 316 gpm, the well was depleting streamflow by approximately 68 gpm, or 0.15 cubic feet per second (cfs). The average creek total Creek flow summed from the South Fork and Shirley Canyon stream gauges during Test 1 was 30.25 cfs. Therefore, well SVPSD#2 captured a maximum of one-half of one percent of Squaw Creek's flow during Test 1.

Figure 8 additionally shows that during an eight hour pumping cycle, well SVPSD#2 captures an average of 1.12% of its total discharge from Squaw Creek. Assuming an average pumping rate of 300 gpm, well SVPSD#2 captures an average of 3.4 gpm, or less than 0.008 cfs during a customary 8-hour pumping cycle.

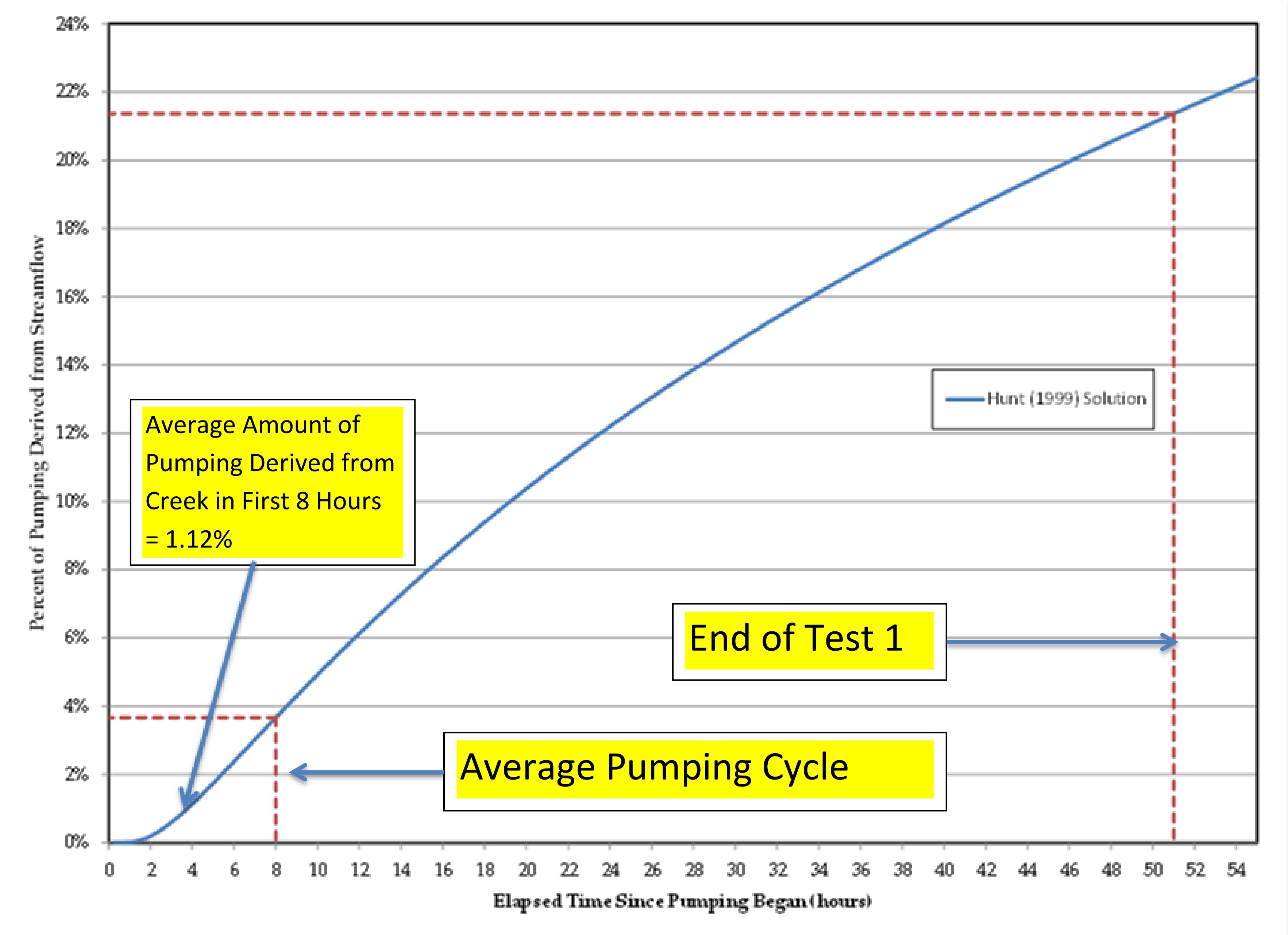

Figure 8 : Streamflow Depletion Curve for Well SVPSD#2

3.4 QUALITATIVE OBSERVATIONS

Two aquifer tests were conducted: one while Squaw Creek was flowing and one while one Creek was dry. The second test, when Squaw Creek was dry, had the least impact from external influences. Therefore, the aquifer parameters calculated from Aquifer Test 2 are likely the most reliable parameters. In particular, the hydraulic conductivity of 235 feet per day is likely a reasonable value for the Squaw Valley aquifer. The true hydraulic conductivity may be less, based on the thickness of the aquifer.

Although not definitive, the drawdown measured in well SVPSD-4R suggests the influence of boundaries at later times during both Aquifer Tests 1 and 2. The potential boundary influences are shown in Figure 9. Figure 9 shows that during Aquifer Test 1, the measured drawdown was less than the theoretical drawdown (shown with the light green Theis curve) at late times. This may be the due to the influence of recharge from Squaw Creek. Although not as clear, Figure 9 also shows that during Aquifer Test 2, the measured drawdown was greater than the theoretical drawdown (shown with the dark green Theis curve) at late times. This may be due to the influence of the basin boundary that lies just beyond the northern edge of Squaw Creek.

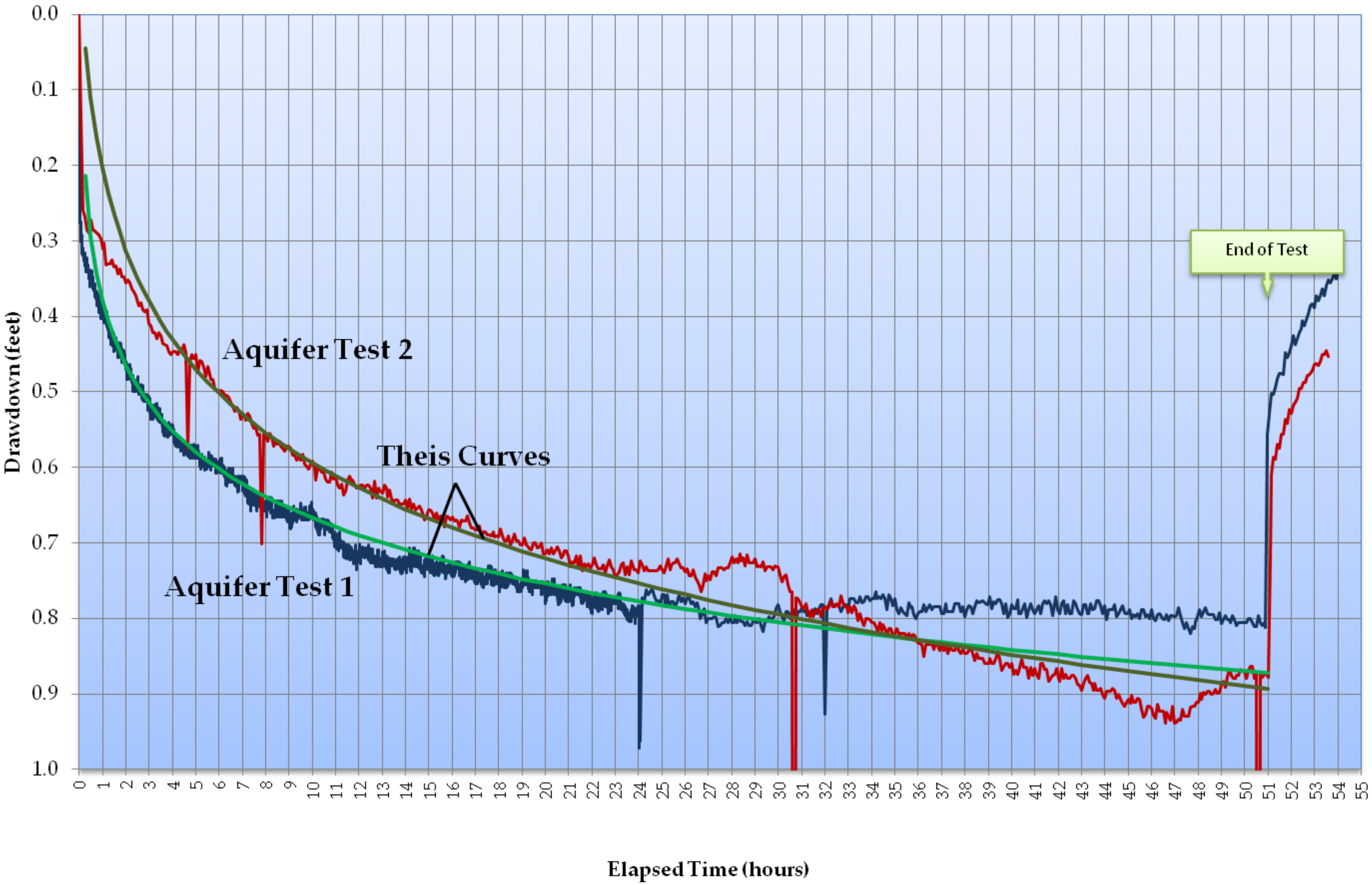

Figure 9: Aquifer Test Drawdowns in SVPSD-4R with Fitted Theis Curves

SECTION 4
CONCLUSIONS

As part of the overall Squaw Valley Creek/Aquifer interaction study, aquifer test results helps quantify the impact of pumping on flows in Squaw Creek. The most significant result from these tests is the quantification of streamflow capture from municipal well pumping. Based on the results of these tests, municipal wells such as SVPSD#2 capture only 4% of their water from Squaw Creek at the end of customary 8-hour pumping cycles. This is approximately equal to 12 gpm, or 0.03 cfs. The amount of water captured by any well will depend on the wells location relative to Squaw Creek.

During Aquifer Test 1, the maximum amount of streamflow captured by well SVPSD#2 after 51 hours of pumping was 68 gpm, or 0.15. This was only on-half of one percent of the flow in Squaw Creek at the time of the test.

Because the reduction in Squaw Creek flows is only a small percentage of pumping from any one well, pumping is only a significant influence on Squaw Creek flows during low-flow times. During most of the spring runoff, pumping reductions on creek flow are insignificant.

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SECTION 5
REFERENCES

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Hunt, B. 1999. Unsteady stream depletion from ground water pumping. *Ground Water*, 37(1), 98-102.

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Theis, C.V. 1935. Relation between the lowering of piezometric surface and the rate and duration of discharge of a well using groundwater storage. *Transactions of the American Geophysical Union*, 16, 519-524.

APPENDIX A: Drawdown Results

This appendix presents plots of the drawdowns at every measurement location during two aquifer tests: one in June 2009 when Squaw Creek was flowing and one in September 2010 when the creek was dry. Accompanying each plot is a brief statement about the observed behavior and whether or not the data were included in the parameter estimation analysis.

SVPSD-4R

Figure A-1 displays the drawdown measured in well SVPSD-4R during both aquifer tests. The drawdowns from this well show a strong and consistent response to pumping. Their curves have a similar and typical shape during pumping, rapid recoveries after the cessation of pumping, and little apparent interference from outside wells. The divergent behavior at later times may reveal the impact of different boundary conditions, as is discussed in the results section of the main report. These data were included in the parameter estimation analysis for both tests.

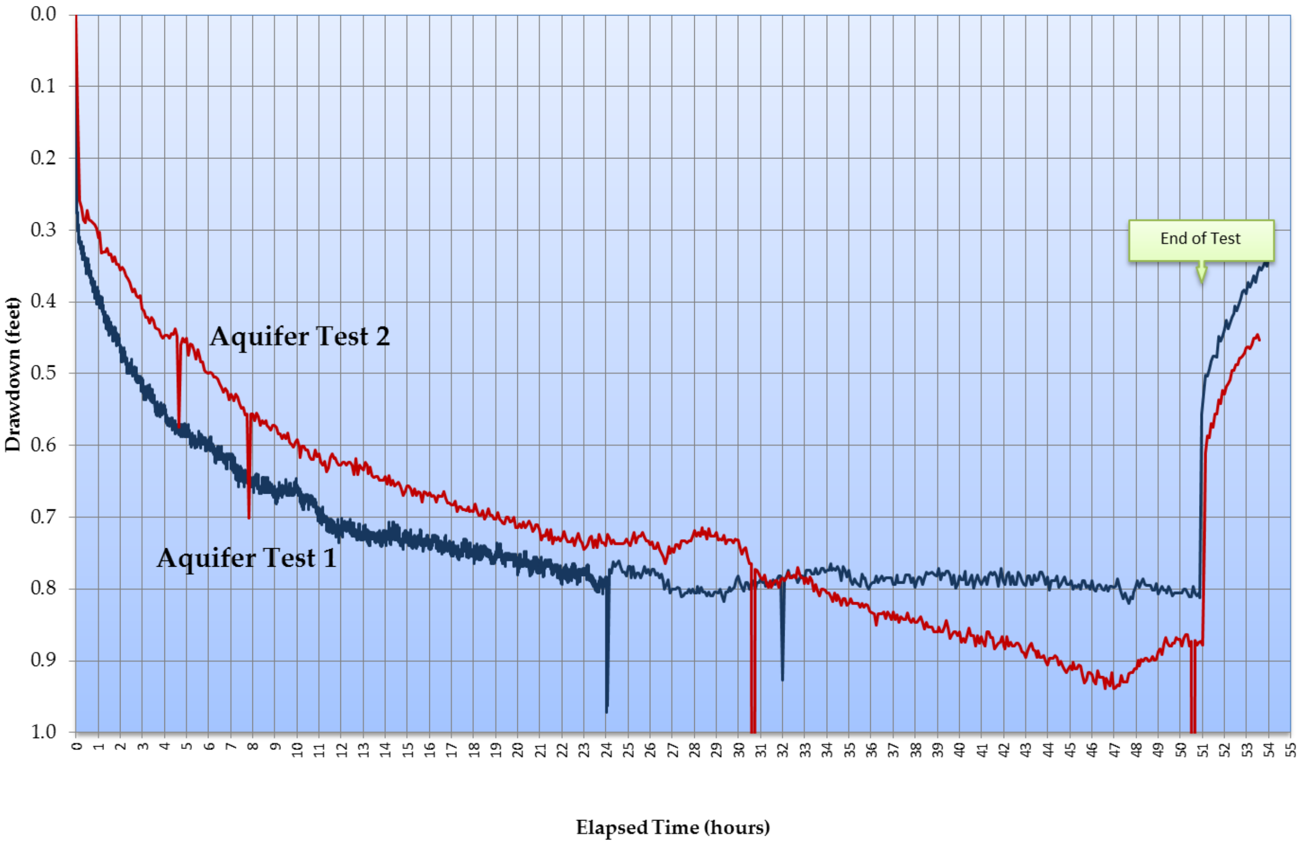

Figure A-1: Drawdowns in SVPSD-4R During Both Aquifer Tests

SVMWC#1

Figure A-2 displays the drawdown measured in well SVMWC#1 during both aquifer tests. Only hand measurements of groundwater level were taken from this well. Although drawdowns increase during pumping and recover afterward, the data in these curves are too sparse to draw conclusions about their consistency or the degree of possible interference. An attempt was made to include these data in the parameter estimation analysis but they added no value to the analysis and were removed.

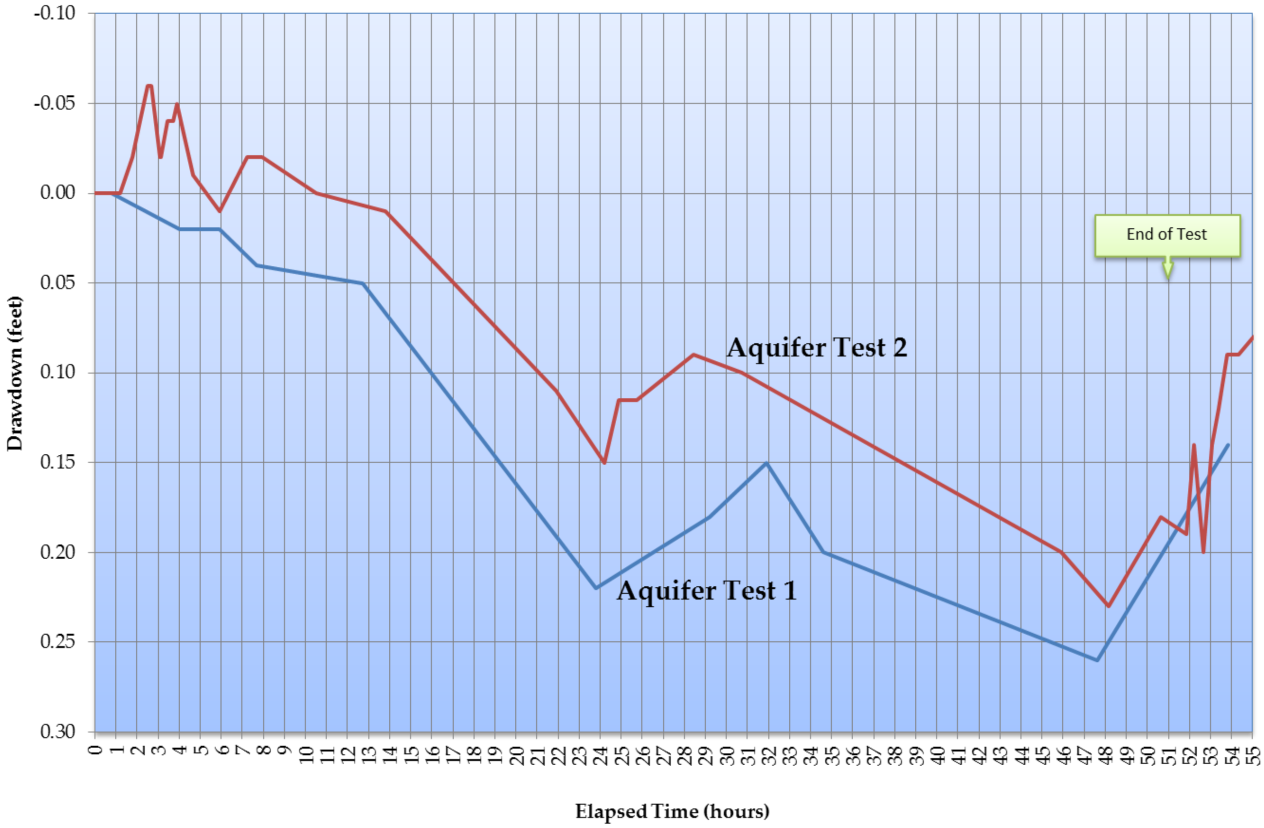

Figure A-2: Drawdowns in SVMWC#1 During Both Aquifer Tests

MW-5S

Figure A-3 displays the drawdown measured in well MW-5S during both aquifer tests along with the difference in the Channel's End stilling well levels during Aquifer Test 1. The drawdown in well MW5S show a response to pumping that is apparent but overlain with background noise. There is also a significant response to head changes in the creek during Aquifer Test 1. These data are thought to have too much interference from the creek and other unknown sources and were not included in the parameter estimation analysis for either test.

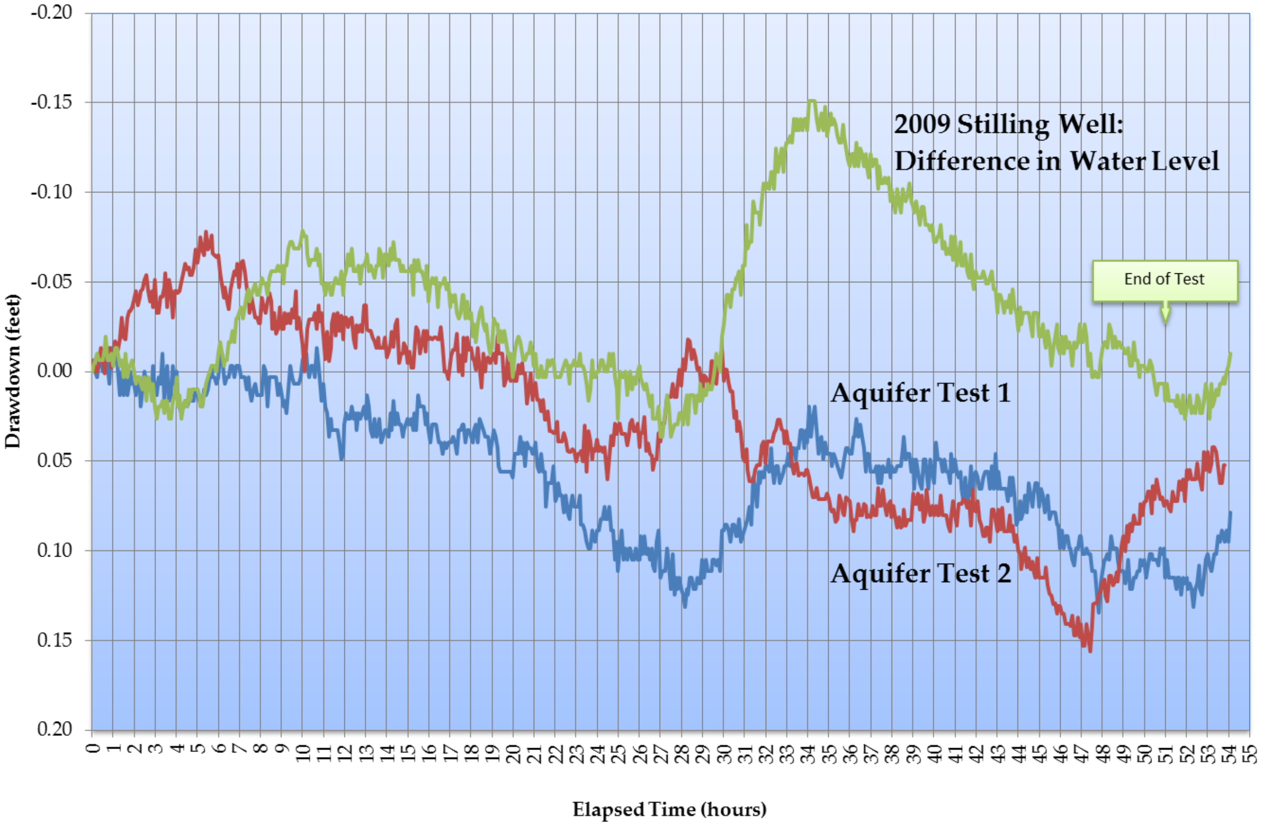

Figure A-3: Drawdowns in MW-5S During Both Aquifer Tests

MW-5D

Figure A-4 displays the drawdown measured in well MW-5D during both aquifer tests along with the difference in the Channel's End stilling well water levels during Aquifer Test 1. The drawdowns from this well show a greater response to pumping than in well MW-5S and a lower relative presence of interference. There is a response to head changes in the creek during Aquifer Test 1, but it has a lower relative influence. These data were included in the parameter estimation analysis for both tests. For Aquifer Test 1, the focus of the analysis was placed on earlier times, when less rapid changes were observed in the creek.

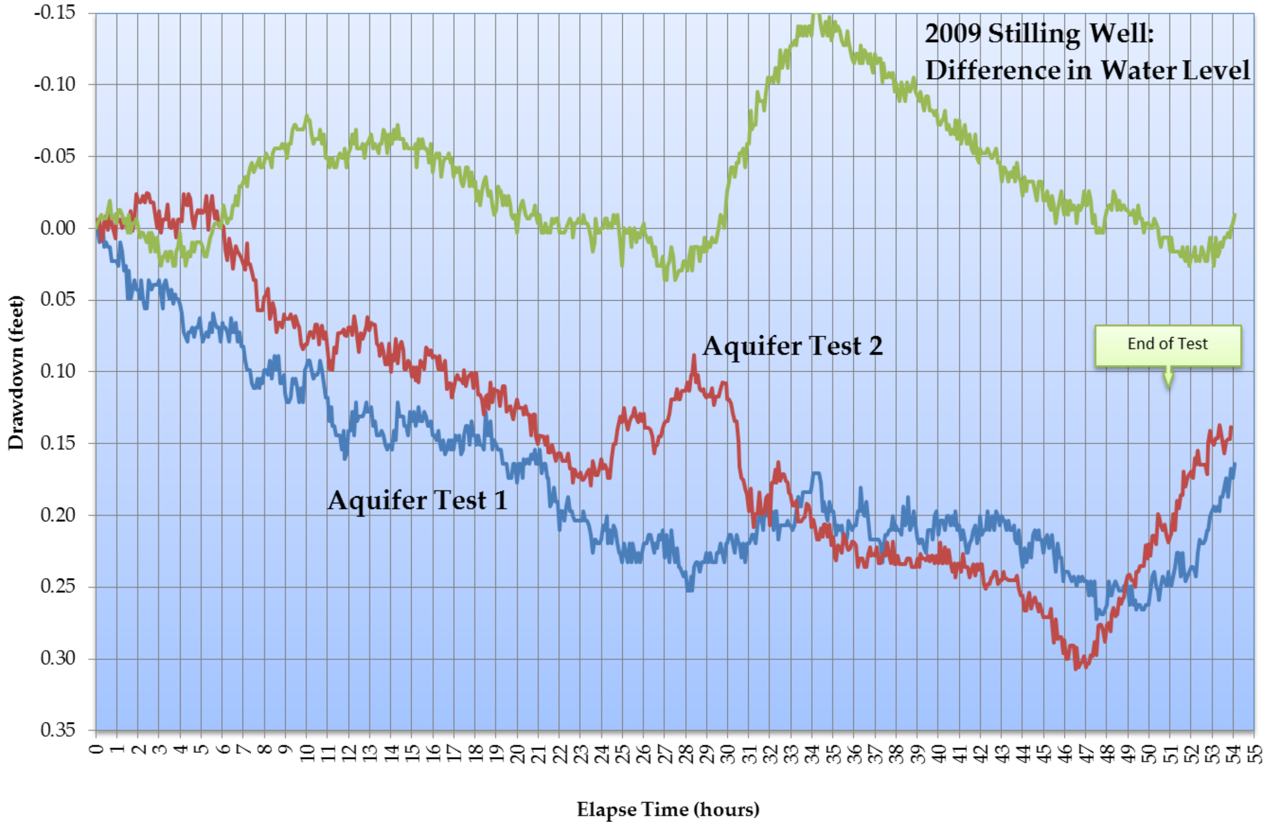

Figure A-4: Drawdowns in MW-5D During Both Aquifer Tests

POULSEN SHALLOW

Figure A-5 displays the drawdown measured in the Poulsen Shallow well during both aquifer tests. The drawdowns from this well show no visible response to pumping from well SVPSD#2. These groundwater levels are likely responding strongly to the nearby pumping well SVMWC#2. These data were not used in the parameter estimation for either test.

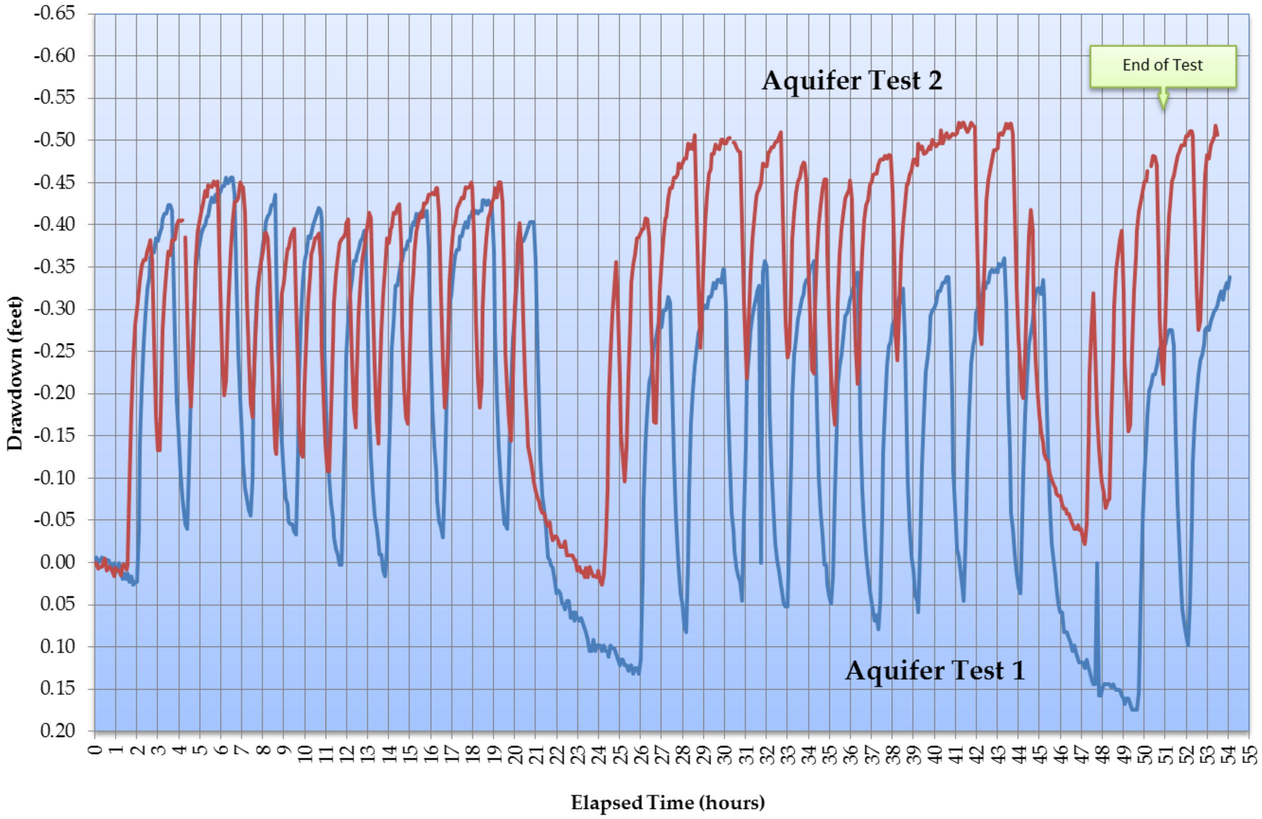

Figure A-5: Drawdowns in Poulsen Shallow During Both Aquifer Tests

POULSEN DEEP

Figure A-6 displays the drawdown measured in the Poulsen Deep well during both aquifer tests. The drawdowns from this well show no visible response to pumping from well SVPSD#2. These groundwater levels are likely responding strongly to the nearby pumping well SVMWC#2. These data were not used in the parameter estimation for either test.

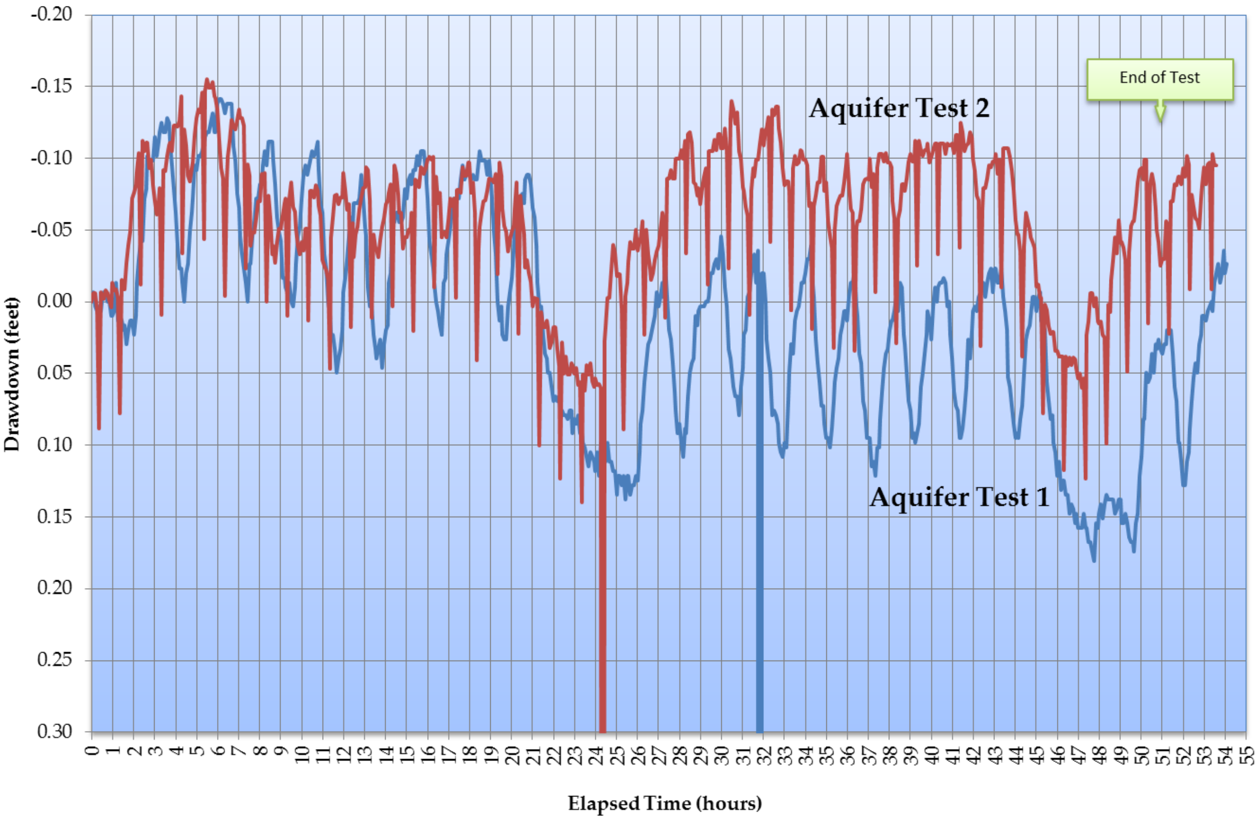

Figure A-6: Drawdowns in Poulsen Deep During Both Aquifer Tests

EAST BRIDGE BANK PIEZOMETER

Figure A-7 displays the drawdown measured in the East Bridge bank piezometer during both aquifer tests along with the difference in the East Bridge stilling well water levels during Aquifer Test 1. The East Bridge bank piezometer shows drawdown during both tests but with behavior that is significantly different than that of the other two nearby piezometers. During Aquifer Test 1, the East Bridge bank piezometer sees little influence from the creek while the East Bridge shallow and East Bridge deep piezometers see a very strong influence. In addition, the East Bridge bank piezometer only experiences about 0.14 feet of maximum drawdown while the East Bridge shallow and East Bridge deep piezometers experience about 0.45 feet. These two observations have led us to believe that the materials around the East Bridge bank piezometer are not hydraulically well connected to the main aquifer in the same manner as the East Bridge shallow and East Bridge deep piezometers. For this reason, these data were not included in the parameter estimation analysis for either test.

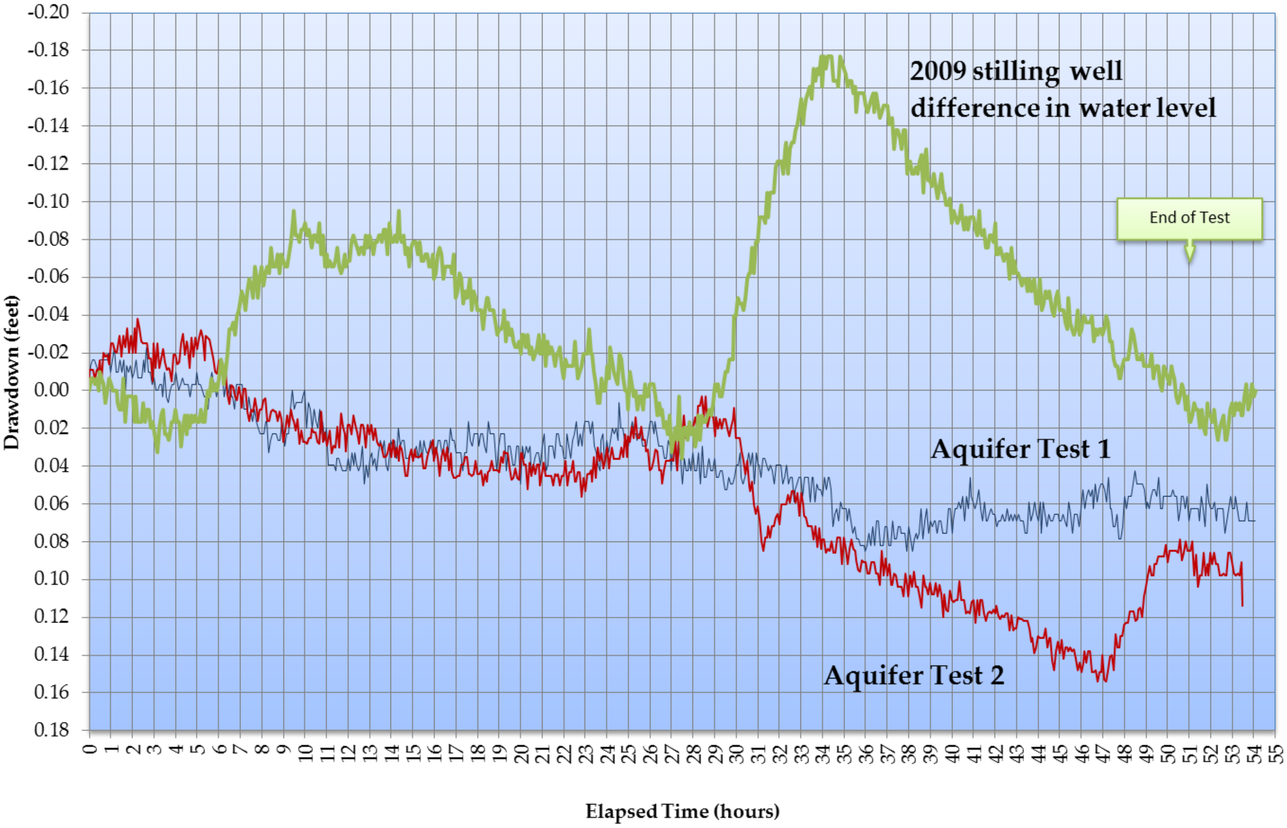

Figure A-7: Drawdowns in the East Bridge Bank Piezometer During Both Aquifer Tests

EAST BRIDGE SHALLOW PIEZOMETER

Figure A-8 displays the drawdown measured in the East Bridge shallow piezometer during both aquifer tests along with the difference in the East Bridge stilling well water levels during Aquifer Test 1. The drawdowns from this well show a consistent response to pumping for Aquifer Test 2, and drawdowns that are strongly influenced by the creek during Aquifer Test 1. These data were included in the parameter estimation for Aquifer Test 2 only.

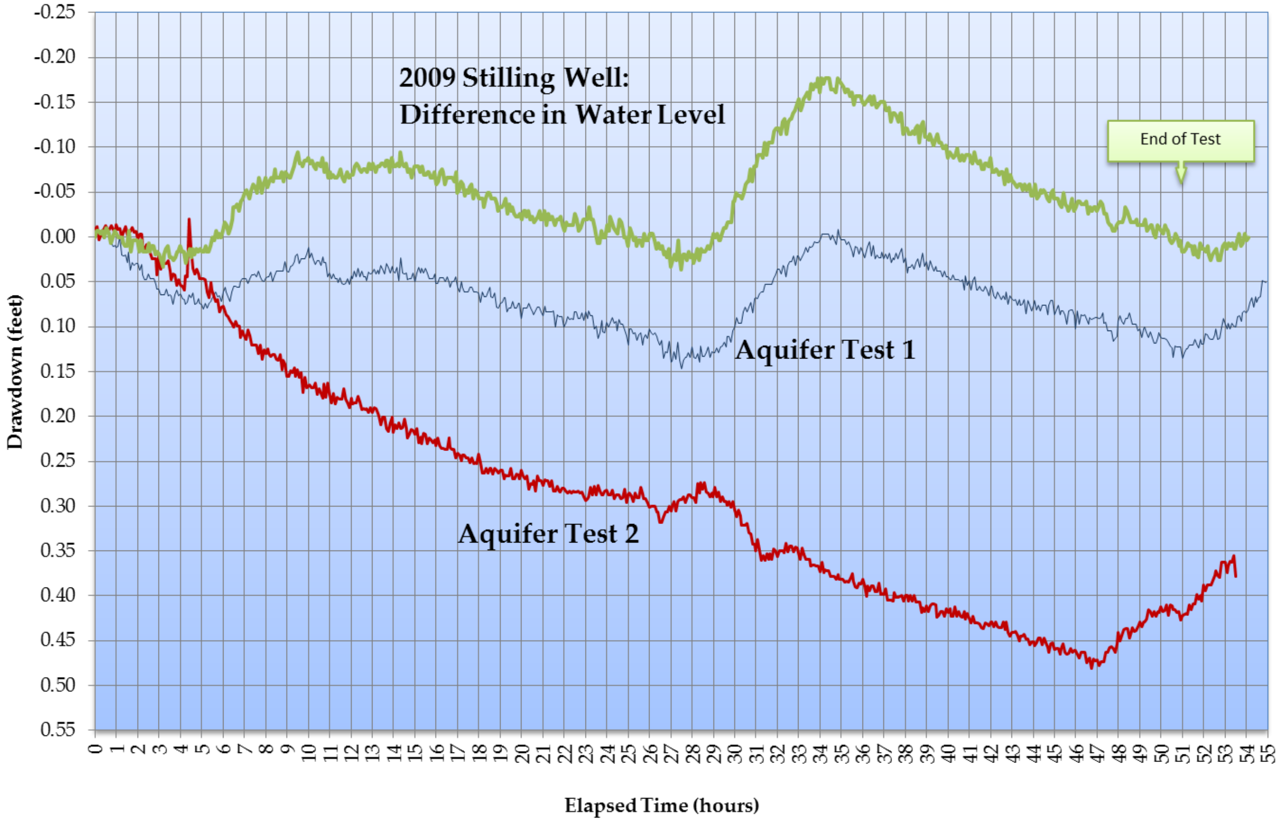

Figure A-8: Drawdowns in the East Bridge Shallow Piezometer During Both Aquifer Tests

EAST BRIDGE DEEP PIEZOMETER

Figure A-9 displays the drawdown measured in the East Bridge deep piezometer during both aquifer tests along with the difference in the East Bridge Stilling Well water levels during Aquifer Test 1. The drawdowns from this well show a consistent response to pumping for Aquifer Test 2, and drawdowns that are strongly influenced by the creek during Aquifer Test 1. These data were included in the parameter estimation for Aquifer Test 2 only.

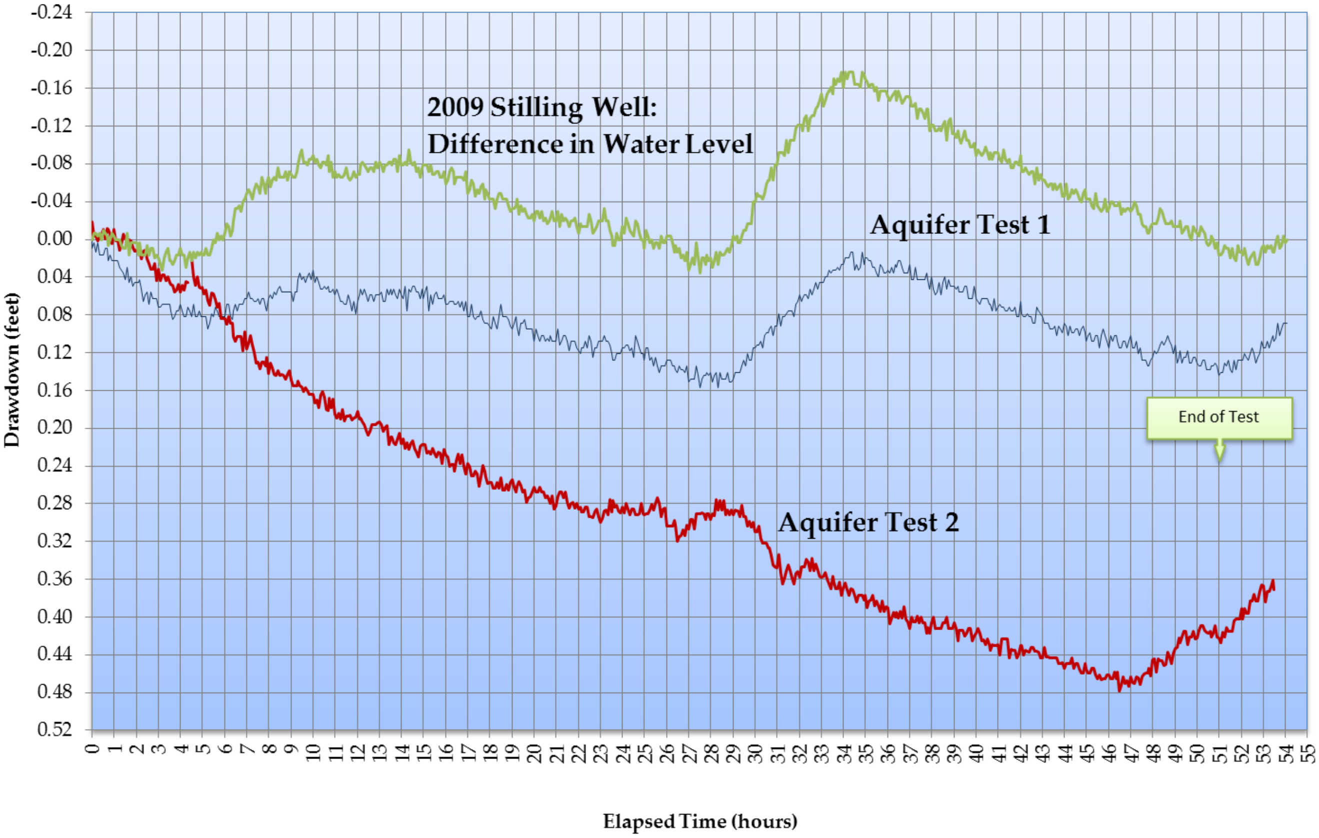

Figure A-9: Drawdowns in the East Bridge Deep Piezometer During Both Aquifer Tests

CHANNEL'S END DEEP PIEZOMETER

Figure A-10 displays the drawdown measured in the Channel's End Deep Piezometer during both aquifer tests along with the difference in the Channel's End Stilling Well levels during Aquifer Test 1. The drawdowns from this well show a response to pumping that is apparent but filled with noise. There is also a strong response to head changes in the creek during Aquifer Test 1. These data are thought to have too much interference from the creek and other unknown sources and were not included in the parameter estimation for either test.

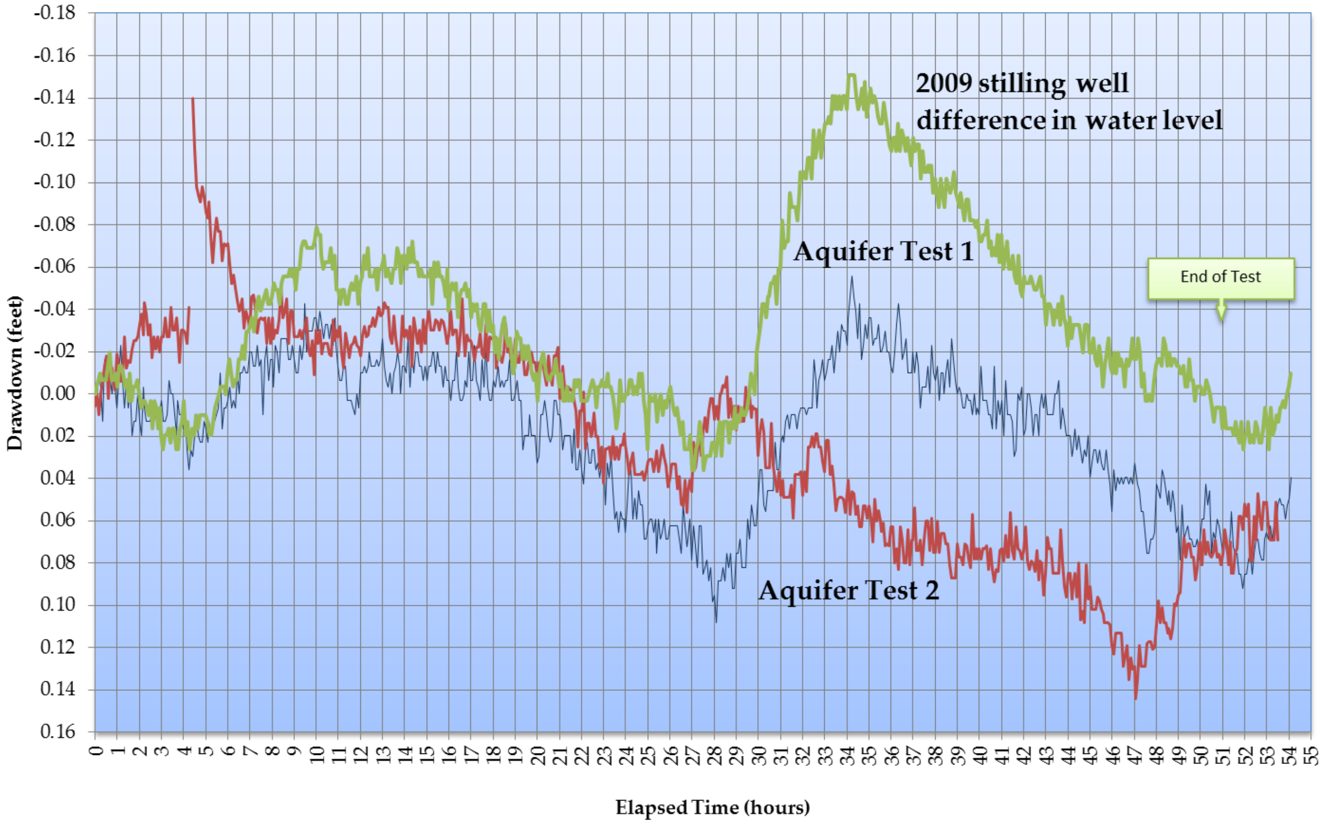

Figure A-10: Drawdowns in the Channel's End Deep Piezometer During Both Aquifer Tests

Squaw Valley Creek/Aquifer Study
Model Update Report

Prepared for:
Squaw Valley Public Service District

November 2013

Prepared by:

HydroMetrics WRI

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ABBREVIATIONS

LLNL	Lawrence Livermore National Laboratory
ME	Mean Error
MAE	Mean Absolute Error
RMSE	Root Mean Square Error
STD	Standard Deviation
SVD	Singular Value Decomposition
SVPSD	Squaw Valley Public Service District

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EXECUTIVE SUMMARY

This report documents a recent update that extends the Squaw Valley groundwater model to include new information obtained between 2004 and 2011. This update extends the model timeframe, includes new measurements for calibration, incorporates new data on stream/aquifer interactions, and migrates the model to new software. Measurements taken since 2004 include groundwater elevation, precipitation, and streamflows. The model was also modified to reflect updated geological data, and to include all wells constructed since 2004.

The main purpose of the model update is to incorporate recently collected data on creek/aquifer interactions, and to verify that the model accurately represents the impact of pumping on Squaw Creek. The impact of pumping on Squaw Creek flows is an important consideration for the Public Service District in fulfilling its role as both water purveyor and environmental steward when estimating the available timing, location, and amount of groundwater pumping in the Valley.

The model was extended from its previous time frame of 1992 through 2004 to simulate conditions between 1992 and 2011. The model was calibrated to match observed water levels over that time frame in both production wells and monitoring wells. An additional analysis was undertaken during calibration to match the simulated stream/aquifer interactions with data collected from two recent studies of Squaw Creek.

The updated and recalibrated groundwater model accurately simulates groundwater levels in Squaw Valley, and matches the measured flows between Squaw Creek and the underlying aquifer quite well. In general, the model simulates groundwater levels and the creek/aquifer interaction in the western portion of Squaw Valley better than the eastern portion. This is consistent with the model objectives of providing a tool for managing groundwater pumping in the western portion of Squaw Valley. The updated groundwater model can be confidently used to develop future groundwater pumping plans that minimize impacts on Squaw Creek.

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SECTION 1
BACKGROUND AND SCOPE

A groundwater flow model of the Squaw Valley Groundwater Basin was created in 2001, and has been updated several times. Prior updates of the Squaw Valley model have been undertaken for a number of purposes, including extending the model timeframe, incorporating new input data, migrating to new software, and adding or modifying features to suit a new modeling objective.

The initial purpose of the Squaw Valley groundwater model was to estimate the operational yield of the groundwater basin, based on the pumping capacities of existing and proposed wells. The purpose of the groundwater model has expanded since its inception. In particular, the effect of groundwater pumping on flows in Squaw Creek has become an important consideration when estimating the available timing, location, and amount of groundwater pumping in the Valley. The groundwater model is expected to incorporate this consideration by accurately reflecting the interaction between Squaw Creek and the underlying aquifer.

Recent studies have attempted to measure the flow between Squaw Creek and the underlying aquifer. One study used heat as a tracer to measure the groundwater flow both in and out of the trapezoidal channel (HydroMetrics WRI, 2013). A second study used Radon measurements to estimate the amount of groundwater flowing into Squaw Creek in the meadow portion of Squaw Valley (Moran, 2013). Incorporating the results of these studies into the groundwater model provides confidence that the model accurately simulates the impact of groundwater pumping on Squaw Creek flows. This updated model allows the Squaw Valley Public Service District (SVPSD) to develop groundwater pumping strategies that minimize impacts on flows in Squaw Creek.

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SECTION 2
MODEL UPDATES AND MODIFICATIONS

A number of model updates and modifications were included in the current modeling effort. These updates were included to improve accuracy and add additional features to the model. Model updates included extending the model period, using an updated model code, updating the geology based on recent drilling activities, and incorporating data from recent Creek/Aquifer interaction studies.

2.1 EXTEND MODEL AND ADD STRESS PERIODS

The transient simulation period was extended from the previous end date of September 30, 2004 to the new end date of December 31, 2011 by adding 87 monthly stress periods. The updated model runs from May, 1992 through December 2011; with 236 monthly transient stress periods and a single initial steady-state period.

A steady-state stress period was added to the beginning of the model. The purpose of this steady-state stress period is to provide an initial condition for the transient simulation; this initial steady-state stress period is not intended to simulate pre-1992 or pre-development conditions. Recharge and streamflow values for this period were set equal to the mean of the values from the transient stress periods. No pumping was applied during this period.

2.2 MIGRATE MODEL TO MODFLOW-NWT

The model was migrated to the recently released MODFLOW-NWT program (Niswonger et al., 2011). This formulation of the MODFLOW model has several new features, the most relevant for this project being better handling of unconfined aquifers where the water table may drop below shallow model layers. This change allowed the model to run more efficiently and allowed inclusion of a thinner top model layer that better represents the mapped hydrostratigraphy.

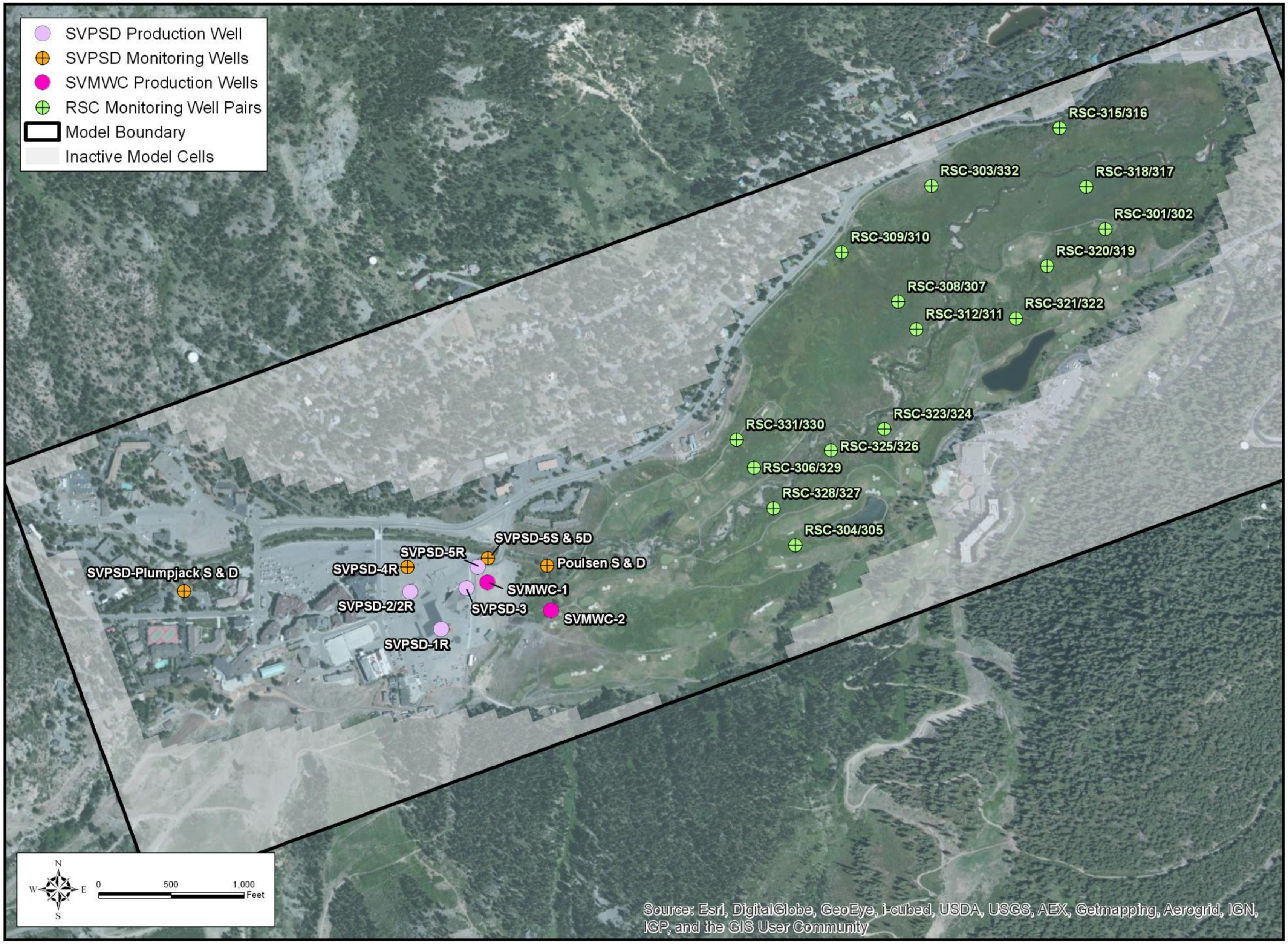
2.3 ADD AND EXTEND GROUNDWATER LEVEL DATA

Groundwater elevation measurements taken from October 2004 through December 2011 were added as additional targets for assessing the performance of the model during calibration. The locations of all wells with groundwater elevation data are shown in Figure 1. Wells installed after October 2004 were added as new observation wells in the model. These wells include:

- SVPSD-1R
- SVPSD-Plumpjack Shallow
- SVPSD-Plumpjack Deep
- Poulsen Shallow
- Poulsen Deep

Several wells have data collected on a daily or sub-monthly basis. In order to resolve these measurements with the monthly stress periods of the model, a single measurement was selected from the end of each month for each of these wells. These selections were reviewed to ensure that they did not capture short term extremes in the hydrograph that the model's monthly stress periods would be unable to reproduce.

Adjustments were made to some groundwater level records from wells SVMWC-1 and SVMWC-2. Written records indicate that at different times both the ground surface and the top of the casing have been used as reference points when reporting depths to groundwater levels. However, many records did not specify which reference point used. For these records reference points were selected in a way that produced both consistency in average groundwater elevations and minimal switching between reference point selections.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

Figure 1: Wells with Groundwater Elevation Data

2.4 INCORPORATE AQUIFER TEST RESULTS

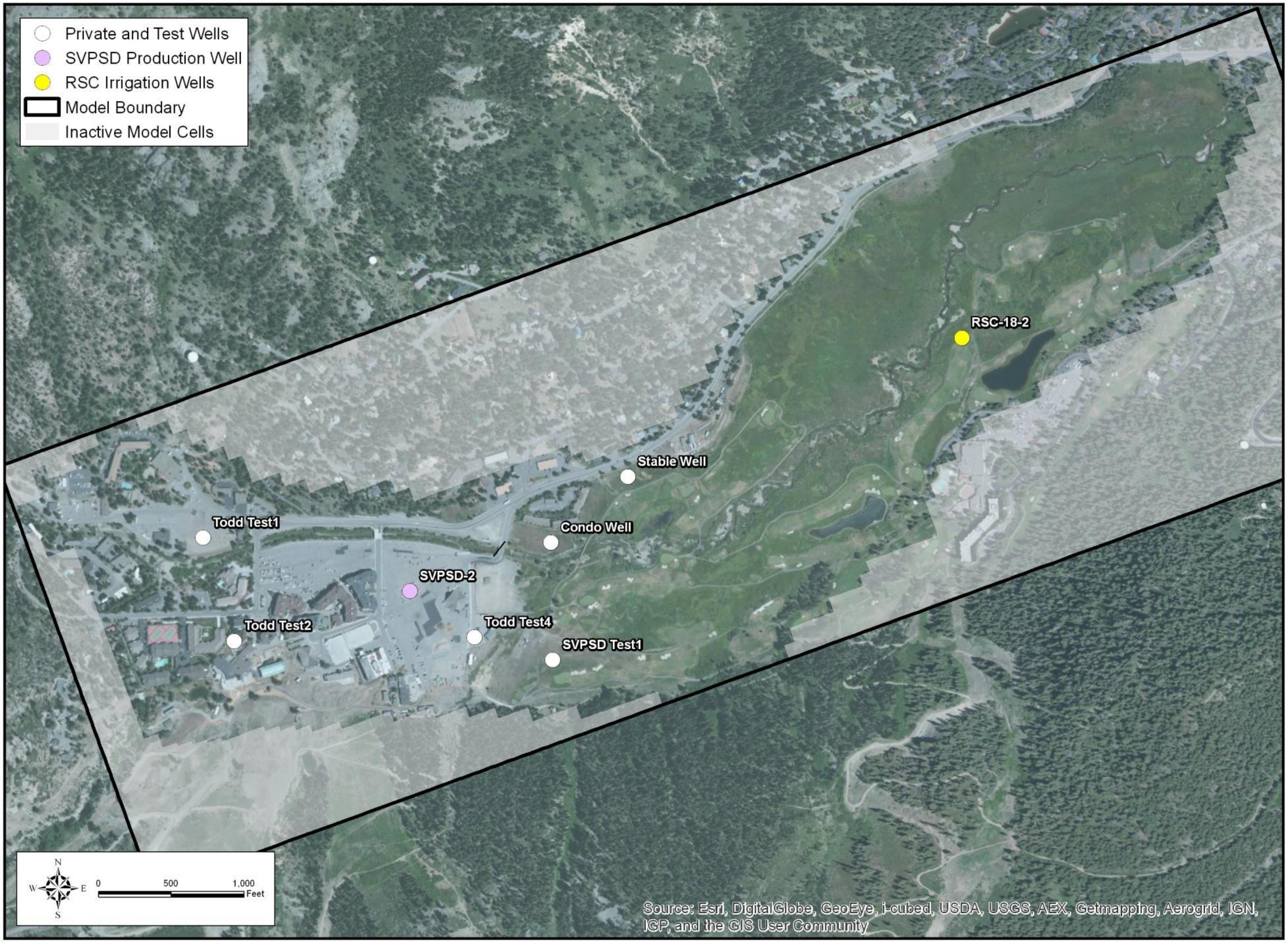
Several aquifer tests have been conducted in the western half of the Squaw Valley aquifer with the goal of inferring hydrogeologic property values. Hydrogeologic property values obtained from these tests help guide the parameter values in the groundwater model.

Four aquifer tests have been conducted in Squaw Valley since 2009. The results of these recent tests were included alongside previous aquifer test results as estimates of hydraulic conductivity. One of these tests was performed by HydroMetrics WRI in September 2010 on the well SVPSD-2 (Hydrometrics WRI, 2013). The other three aquifer tests were recently conducted by Todd Engineers on wells Test Well 1, Test Well 2, and Test Well 4.

The recent aquifer tests complement previous aquifer tests conducted in the western side of Squaw Valley. Not all previous aquifer tests were used to develop hydrogeologic parameter estimates. HydroMetrics WRI reviewed the list of previous aquifer tests and selected a subset of four reliable tests. These data were included alongside the data of the four more recent aquifer tests, resulting in a set of eight estimates. The locations of all eight aquifer test wells are shown on Figure 2, and their hydraulic conductivity results are summarized in Table 1.

Table 1: Aquifer Tests Results Used to Guide Parameter Values

Well Name	Hydraulic Conductivity (feet per day)
SVPSD-2	235
Todd Test Well 1	192
Todd Test Well 2	184
Todd Test Well 4	93
Condo Well	26
RSC 18-2	40
Stable Well	67
SVPSD Test Well 1	103



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

Figure 2: Wells with Aquifer Test Data

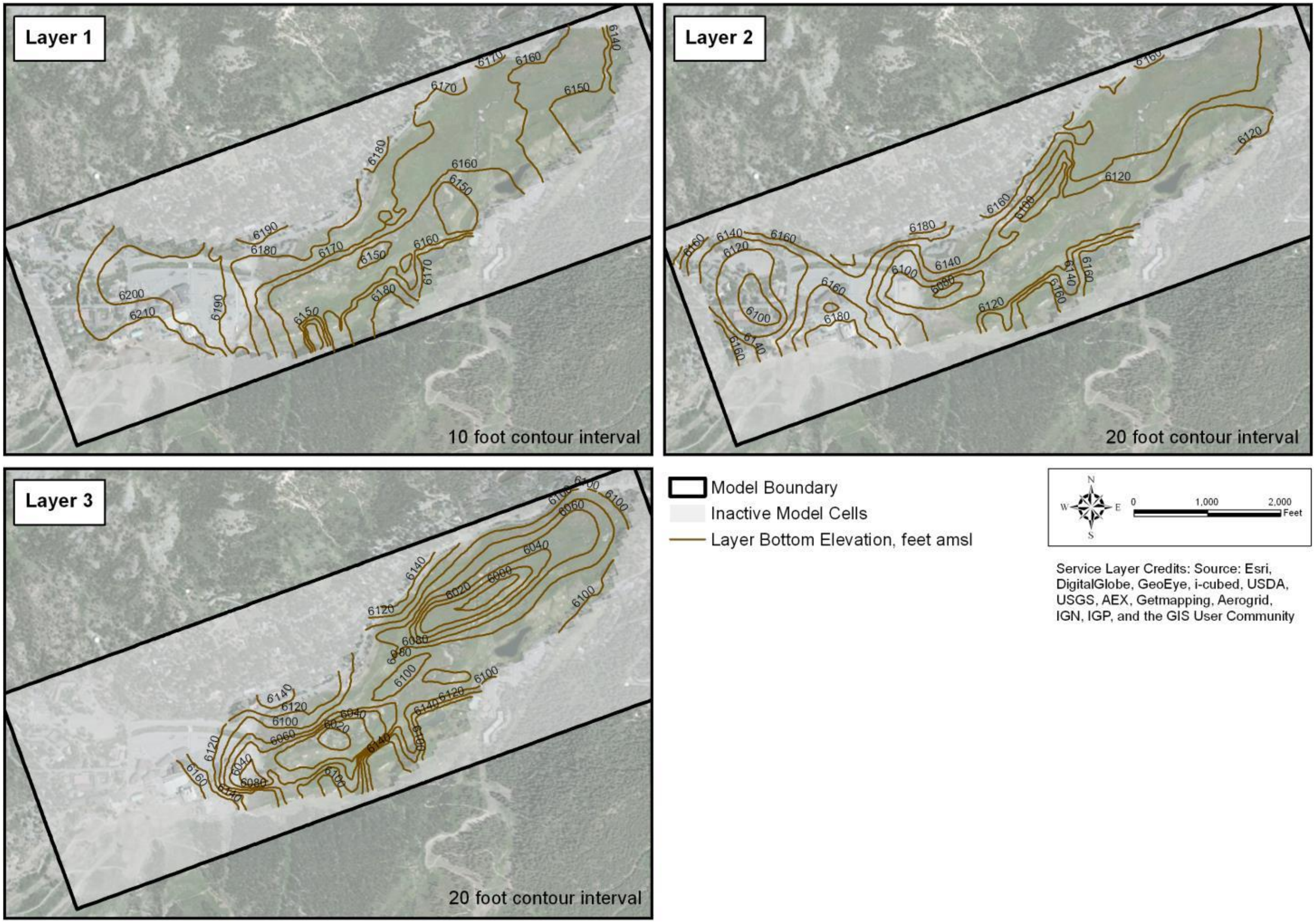
2.5 UPDATE HYDROSTRATIGRAPHY

Based on existing and new geologic data, Todd Engineers developed new maps of the elevation and extent of the three hydrostratigraphic units identified in the Squaw Valley basin. These mapped surfaces were used to adjust elevations of the three model layers. Some adjustments to these surfaces were required to ensure that all observation wells and pumping wells were included in the model without changing their location or depth. The updated extents and bottom elevations for the three model layers are shown in Figure 3.

2.6 ADJUST FAULTS

Several faults were included in the previous model as barriers to the horizontal flow of groundwater. These barriers were aligned with faults that have been mapped across the valley by Schweickert et al. (2000) and were included in the model after a significant groundwater level drop was observed between wells SVPSD-2 and SVMWC-1, which are located on opposite sides of the middle fault. Additional groundwater level data from new and old wells in the same area indicate that a drop in groundwater levels does occur, but is not as dramatic as in the older data. Sufficient data do not exist to substantiate such behavior near the other faults. To simplify the model, the faults that could not be substantiated with groundwater elevation data were removed from the model.

The fault lying between wells SVPSD-2 and SVMWC-1 was left in the model with a slight adjustment in position to better match the fault's mapped orientation. A comparison of the modeled fault and the mapped faults are shown on Figure 4. The conductance of this barrier was allowed to vary during calibration of the model.



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

Figure 3: Model Layer Bottom Elevations

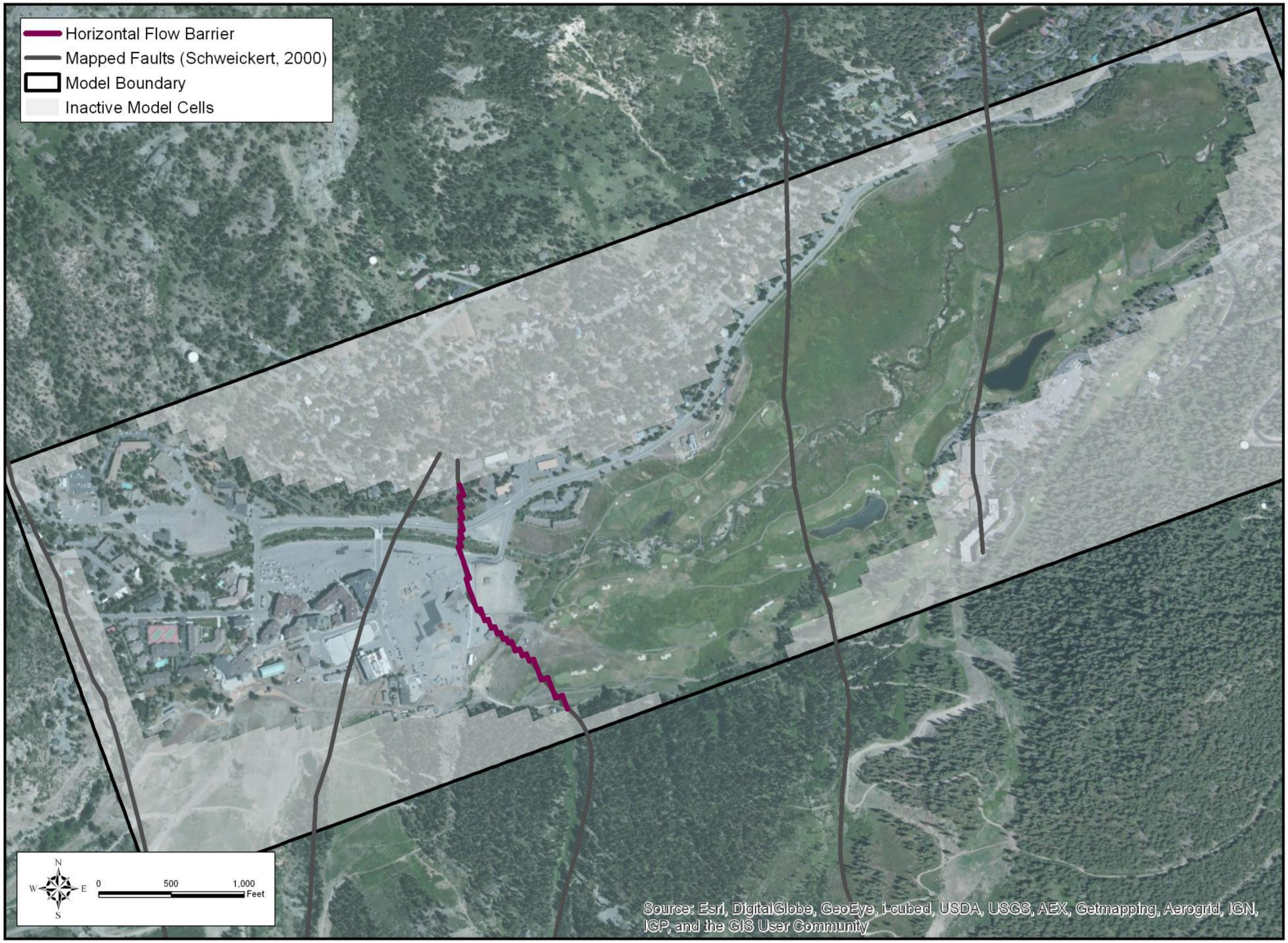


Figure 4: Mapped Fault Traces (Schweickert et. al, 2000) and the Modeled Horizontal Flow Barrier

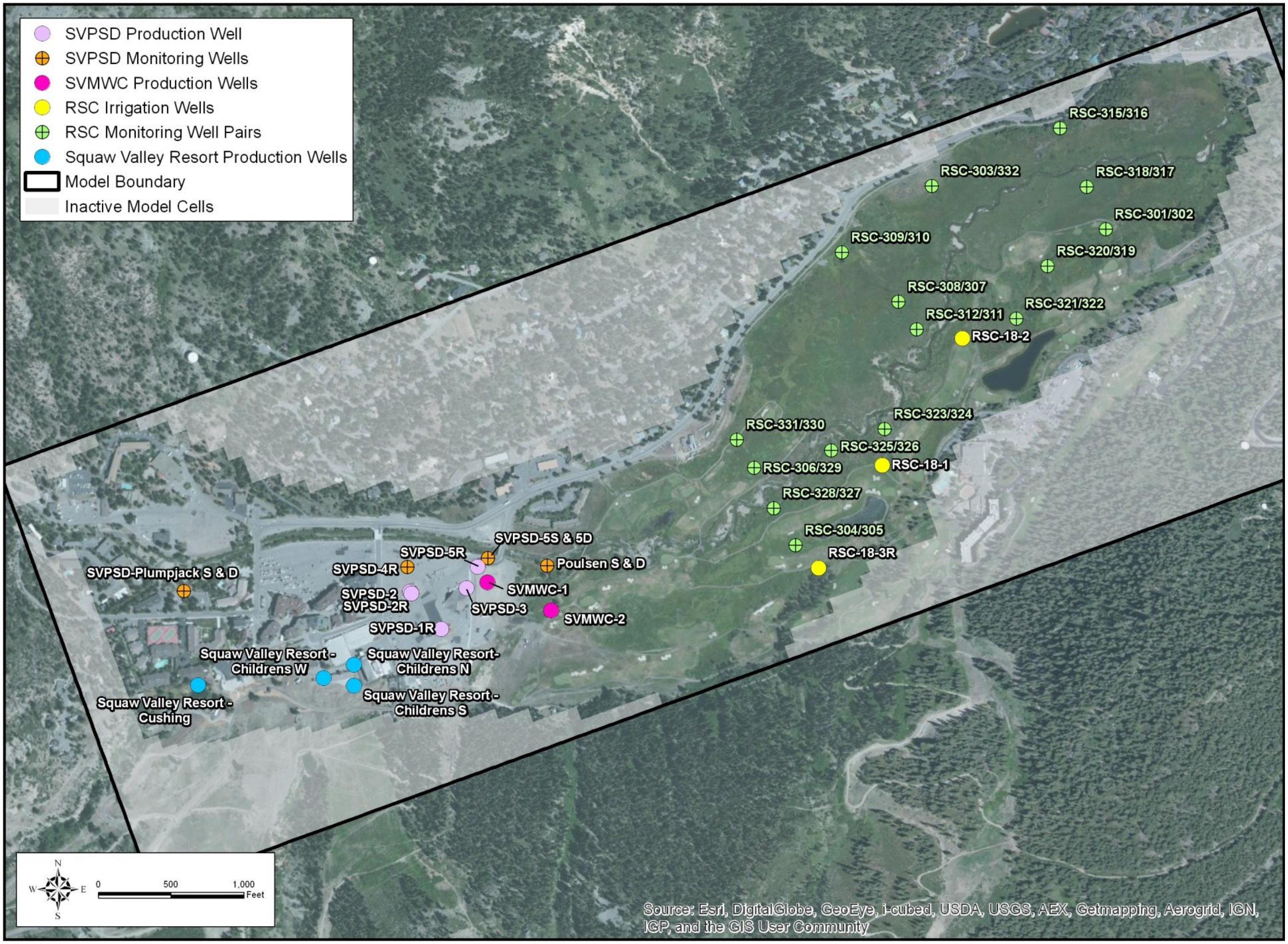
2.7 UPDATE PUMPING

Groundwater pumping recorded from October 2004 through December 2011 was added to the model. Wells installed after October 2004 were added to the model with their recorded monthly pumping rates. The locations of all production wells are shown along with all monitoring wells on Figure 5. Historical pumping rates by entity are shown on Figure 6.

Pumping rates from wells 18-1, 18-2, and 18-3R are not individually recorded. The water from these wells is discharged into a pond for temporary storage, and water volumes are only measured for the water that is drawn from the pond for distribution. For the previous model, a strategy was developed to allocate the lake extractions to pumping at wells 18-1, 18-2, and 18-3R. Mr. Eric Veraguth, the Director of Golf and Ski for The Resort at Squaw Creek suggested a simpler method for allocating the total pumping between wells 18-1, 18-2, and 18-3 that is equally valid (Todd Engineers, 2013). In this new method, the total pumping is split as follows:

- 16% of pumping comes from well 18-1
- 41% of pumping comes from well 18-2
- 43% of pumping comes from well 18-3R

The pumping wells in the model were migrated from the basic well (WEL) package to the multi-node well package (MNW2). This package includes many additional options for simulating the impact of wells, especially for wells that are screened over multiple layers. The major features of the MNW2 package used in the Squaw Valley model are the ability to draw water from multiple model layers, the ability to model groundwater level drops between the aquifer and the well bore, and the ability to limit pumping when groundwater levels drop below a pump intake. The last two features are only used to make future predictions; they were turned off during calibration in order to uphold the proper water balance of the model.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

Figure 5: Production and Monitoring Wells/

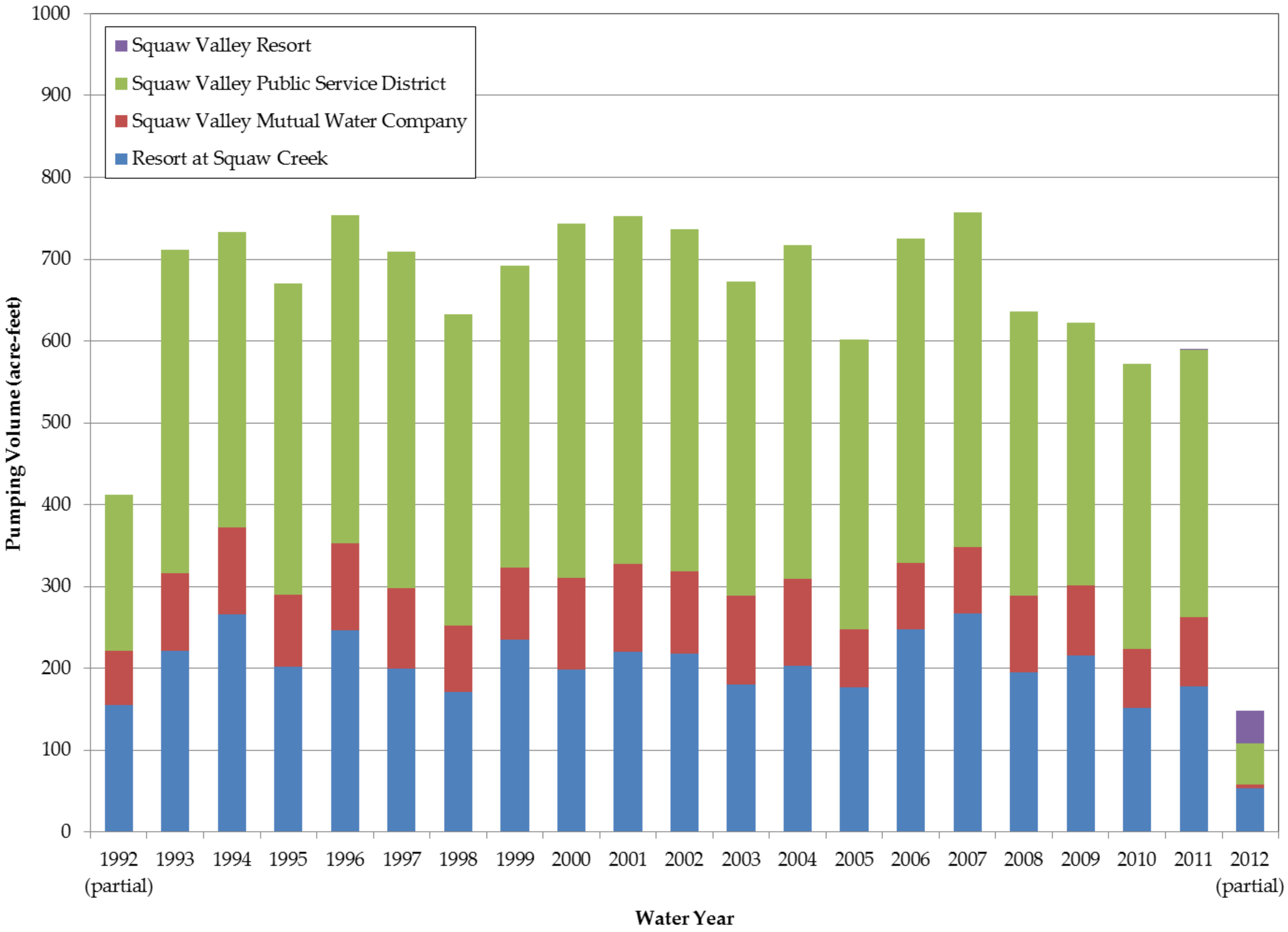


Figure 6: Pumping Rates during the Simulation Period

2.8 EXTEND AND UPDATE STREAMFLOW

Data needed to simulate flows in Squaw Creek include streamflows coming from the South Fork of Squaw Creek and Shirley Canyon, as well as parameters that define how much water leaks in and out of Squaw Creek. The streamflow data were extended to the new model periods, and some adjustments were made to the streambed hydraulic properties. For the trapezoidal channel portion of the creek, the streambed parameters of vertical hydraulic conductivity, width, and thickness were adjusted to match the results of the recent study on stream/aquifer interaction (HydroMetrics WRI, 2013). The streambed conductance parameters for the Shirley Canyon segment and the South Fork Squaw Creek segment were included as adjustable parameters during the model calibration. All other stream segment properties were unchanged. Streambed parameters remain fixed for the entire model simulation.

Monthly streamflows entering Squaw Valley were updated for the two branches that enter the western side of the model and for the point of upwelling located near well 18-3R. These data are from stream gage observations taken at three locations in Squaw Creek The rates of upwelling are determined using a previously established relationship between the flow in Squaw Creek and rates of upwelling. Before 2004, streamflow measurements were unavailable and the streamflow values used in the model were estimated through correlation to a stream outside of Squaw Valley. Because the post-2004 streamflow data are more accurate than the pre-2004 streamflow estimates, the model will likely perform better for the time period after 2004.

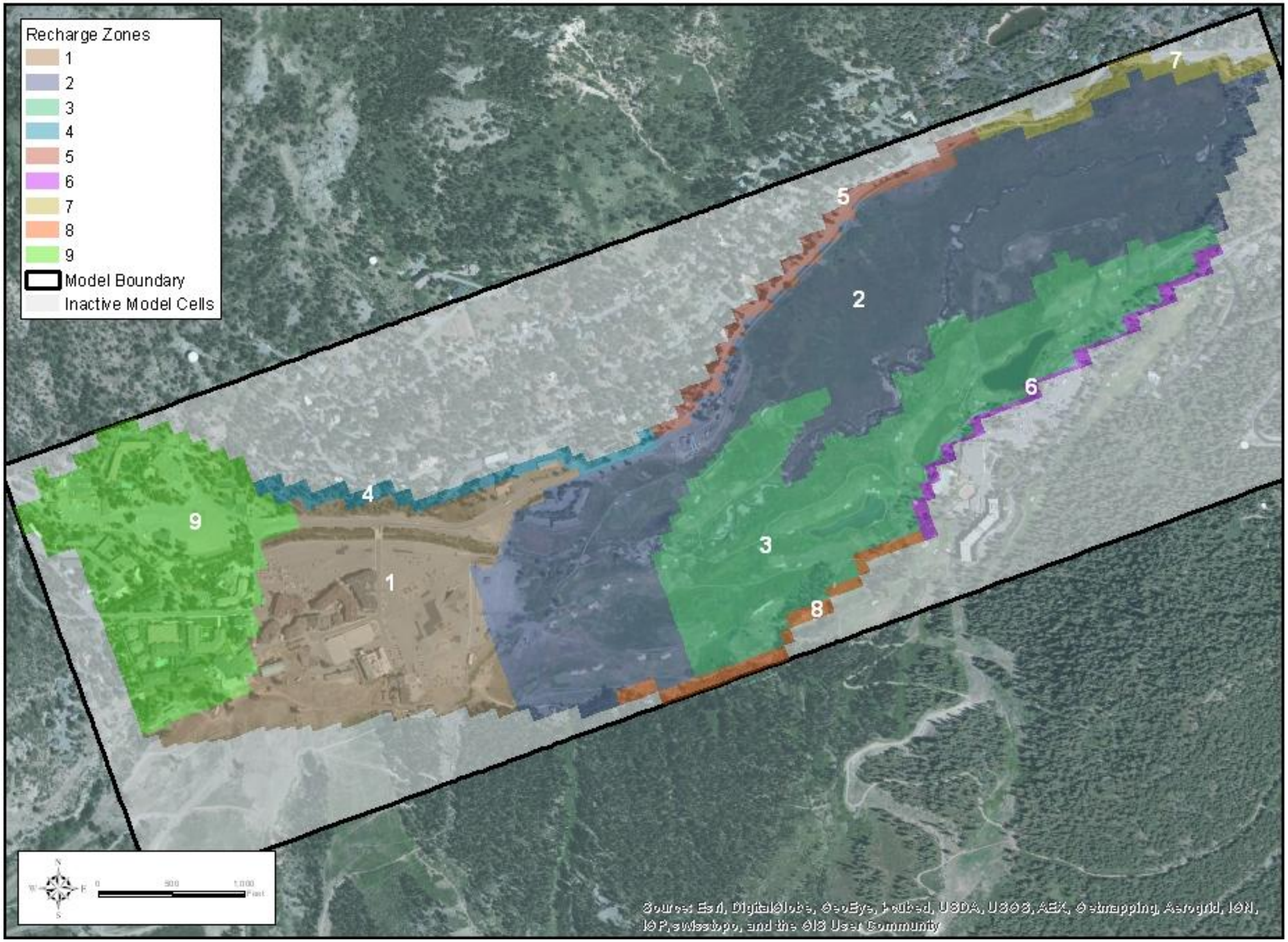
2.9 EXTEND RECHARGE

A water accounting system that allows simulation of multiple recharge sources was developed for the previous model. Nine sources of recharge were identified. Nine zones were established that receive recharge from different combinations of the nine sources. These zones are shown on Figure 7. The sources of each zone are shown in Table 2. This technique was applied to the current model using updated values of precipitation, pumping, irrigation, and sewer flow measurements.

Table 2: Recharge Sources and Zones

Source	**Recharge Zone**								
	1	2	3	4	5	6	7	8	9
Rainfall - western basin	X			X					X
Rainfall - eastern basin		X	X		X	X	X	X	
Irrigation return - golf course			X						
Irrigation return – SVWMC				X	X	X			
Irrigation return – SVPSD							X		X
Pipe losses – SVWMC				X	X				
Pipe losses – SVPSD				X	X		X	X	X
Sewer inflow and outflow				X	X	X	X		X

Rainfall data have been collected for the past 50 years from the Davis rain gauge located behind 1810 Squaw Valley Road. Recently, rainfall data collection has transitioned to the new Nova Lynx rain gauge that was installed in the same location. In 2008 the Nova Lynx gauge began collecting precipitation measurements, and in 2011 measurements from the previously used Davis gauge were no longer reported. Data from the overlapping years of 2008 - 2010 showed that the new gauge measured higher levels of rainfall than the old gauge. The data records for each gauge, and a comparison of their precipitation readings for the overlapping period, are shown on Figure 8 and Figure 9. In order to maintain consistent precipitation values for estimating recharge to the model, the old Davis gauge measurements are used for all months until they become unavailable in 2011. For the year of 2011, a correlation was established between the values of the new and old gauges, and was used to produce a Davis gauge estimate of precipitation for that year. The final precipitation history used is shown on Figure 10 and a plot showing the correlation between the two gauges is shown on Figure 11.



Sources: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 7: Recharge Zones

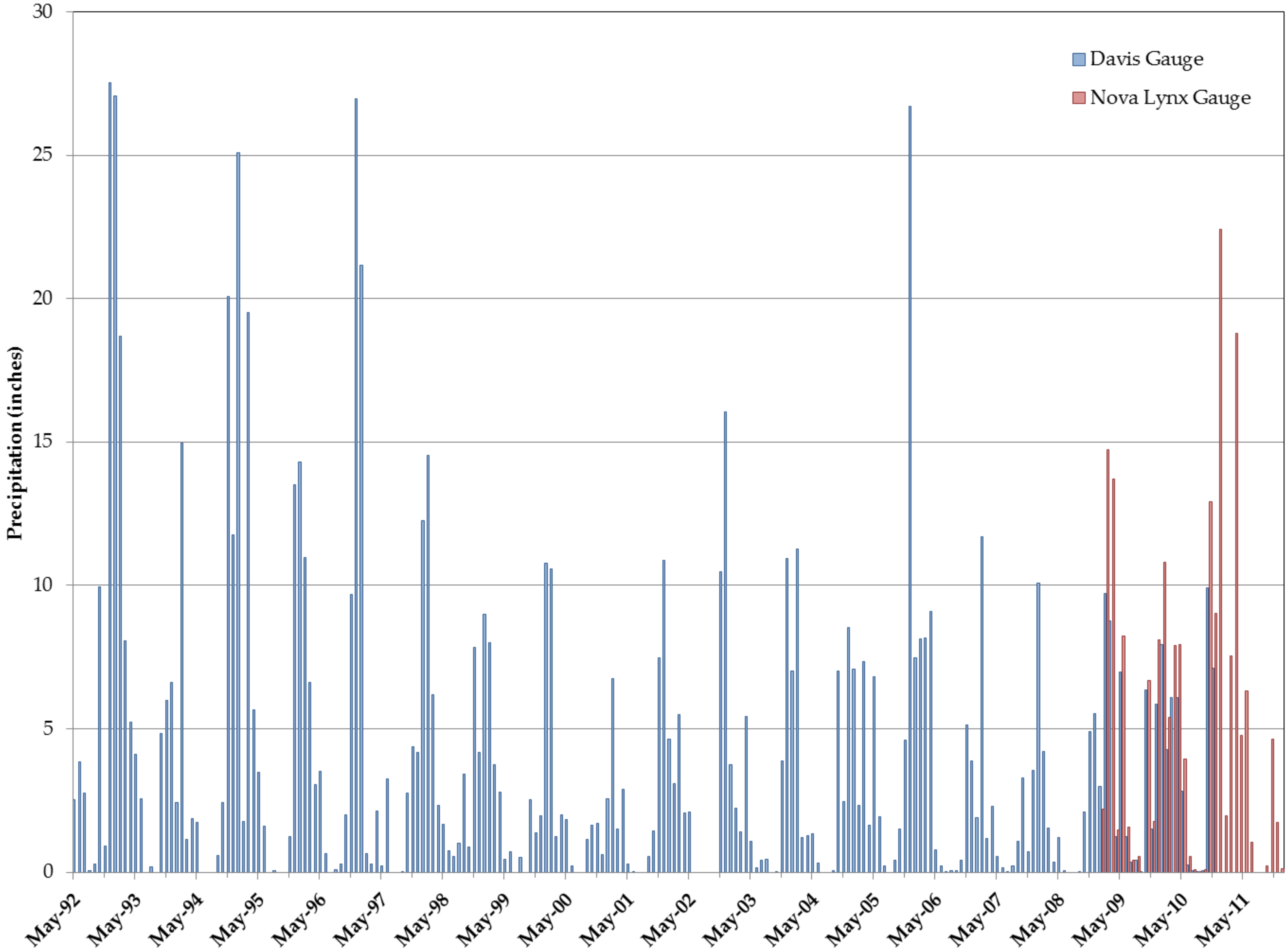


Figure 8: Davis Gauge and Nova Lynx Gauge Precipitation Records

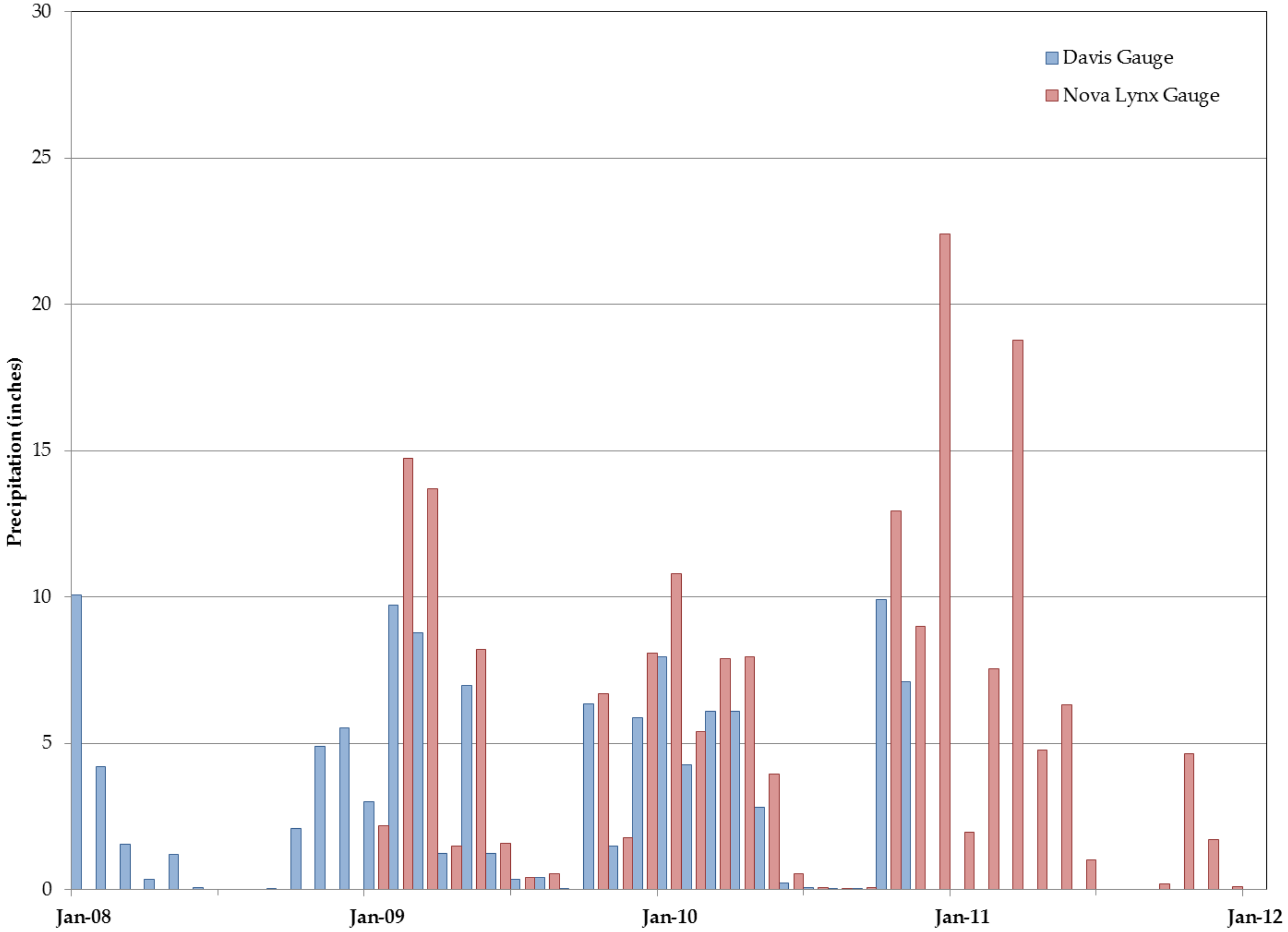


Figure 9: Comparison of Davis and Nova Lynx Gauge Readings during Period of Data Overlap

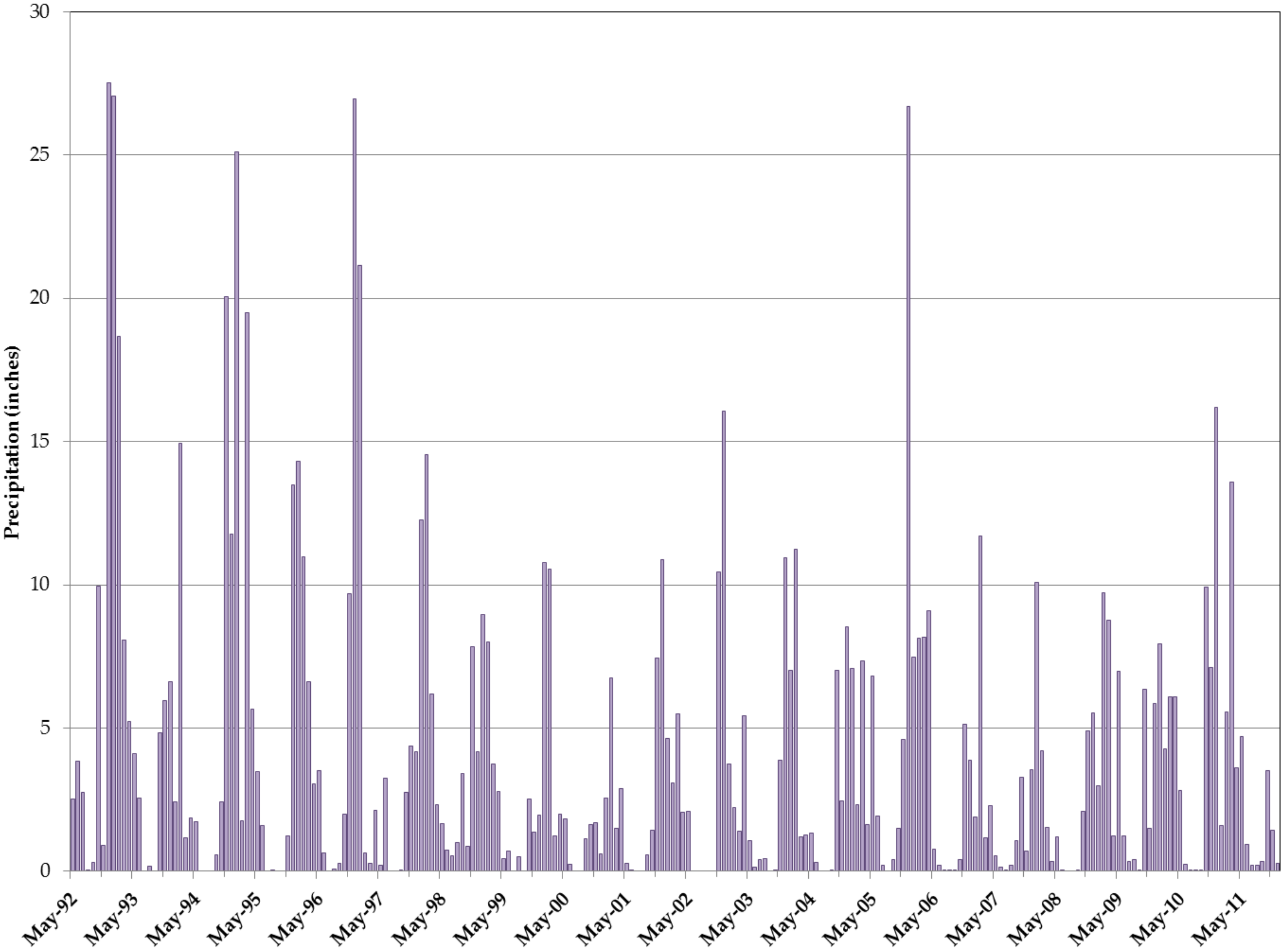


Figure 10: Final Precipitation Record Used in Model

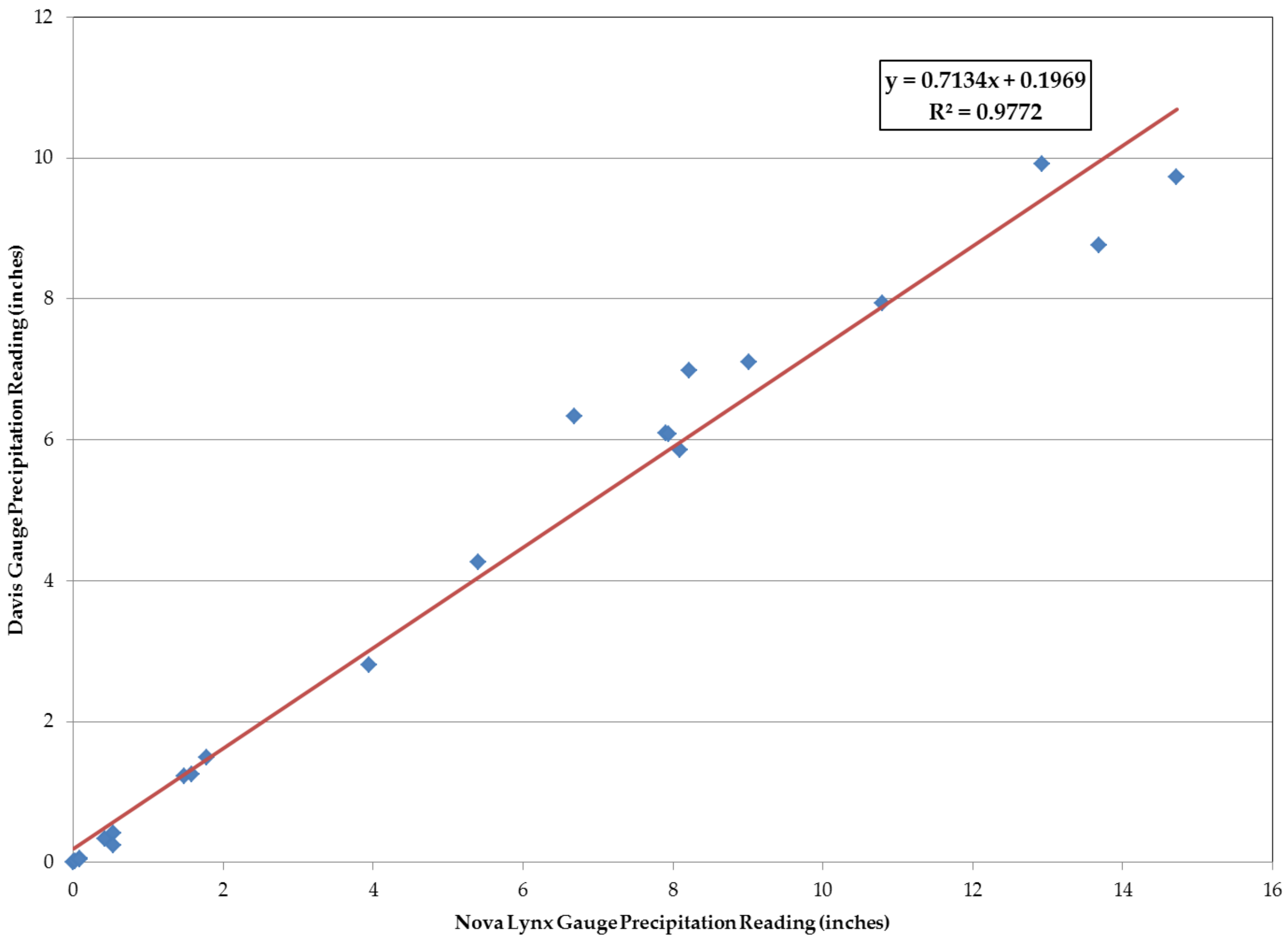


Figure 11: Davis Gauge and Nova Lynx Gauge Data Correlation

2.10 REDEFINE HYDRAULIC PROPERTY ZONES

The previous model included 10 different zones in which values of the hydraulic properties hydraulic conductivity, specific storage, and specific yield were uniform. These zones were eliminated in favor of a pilot point approach for distributing the values of hydraulic properties across the model (Doherty, 2003). This approach is described in section 3.4 below.

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SECTION 3
MODEL CALIBRATION

3.1 APPROACH

Calibrating the regional groundwater flow model involved successive attempts to match model output to measured data from the calibration period. Simulated groundwater elevations were compared against available observed groundwater elevations. The model was considered calibrated when simulated results matched the measured data within an acceptable measure of accuracy, and when successive calibration attempts did not notably improve the calibration statistics. Calibration was conducted by varying relatively uncertain and sensitive parameters such as horizontal and vertical hydraulic conductivities, over a reasonable range of values. Parameters varied during calibration included:

- Horizontal conductivity
- Vertical to horizontal conductivity
- Specific yield
- Specific storage
- Stream leakage
- Fault conductance

3.2 CALIBRATION PERIOD

The primary criterion for choosing the appropriate calibration period was the availability of a relatively complete set of data. The necessary data included complete pumping data, recharge data, and groundwater elevation data from the network of groundwater monitoring wells. Taking into account these criteria, we chose the period from May 1992 through December 2011 for calibration.

As discussed earlier, the post-2004 streamflow data are more accurate than the pre-2004 streamflow estimates, and the model will likely perform better for the time period after 2004. To reflect the improvement in the data that began in 2004, the groundwater elevation observations after 2004 were given a ten times larger weight in the calibration than those observations prior to 2004.

3.3 STRESS PERIODS

Stress periods define a time period in the groundwater model over which hydraulic stresses such as pumping and recharge are held constant. Stress period selection depends on the model objectives and the time frame of interest. The primary objective of the model is to assist with groundwater management strategies and simulating impacts from potential water projects. Because seasonal fluctuations in groundwater elevations are important in groundwater management, the stress periods must be at least seasonal. Based on the existing data and model objectives, monthly stress periods were chosen. These stress periods allow adequate resolution of seasonal groundwater level fluctuations while performing the simulations in a reasonable amount of time.

3.4 PILOT POINT METHOD FOR MODEL CALIBRATION

A pilot point approach, rather than a zoned conductivity approach, was used to distribute aquifer parameters during calibration. The pilot point approach results in a smoothly varying hydraulic conductivity field. Doherty (2003) describes the methodology for the use of pilot points in groundwater model calibration. Using this method, the values of aquifer hydraulic properties are estimated at the locations of a number of points spread throughout the model domain. Hydraulic properties are then assigned to the model grid through spatial interpolation from those points (Doherty, 2007). Spatial interpolation from pilot points to the finite difference grid defines a hydraulic property array on a cell-by-cell basis. Pilot points minimized the need to guess where unmapped heterogeneity might exist within a model domain ahead of the calibration process. Instead, the calibration process informs where heterogeneity exists.

Prior to estimating any hydraulic parameters, the pilot points were selected manually based on following criteria (Doherty, 2002):

1) More pilot points were placed where there are more data;
2) Pilot points were placed between data points in order to calibrate to head difference between wells;
3) Pilot points were placed in between wells and outflow boundaries.
4) Pilot points were placed to eliminate big gaps between adjacent pilot points;

In addition, pilot points for horizontal hydraulic conductivity were placed at locations in which we had obtained estimates of hydraulic conductivity from aquifer tests.

Between 18 and 78 pilot points were selected for each layer. The pilot points are used to estimate horizontal hydraulic conductivity, ratio of horizontal to vertical hydraulic conductivity, specific yield, and specific storage. Layer 1 was treated as homogeneous with respect to specific storage and layer 3 was treated as homogenous with respect to specific yield. The values in these two instances were specified and omitted from the parameter estimation process.

The use of pilot points methodology results in 480 parameter values that can be varied during calibration. PEST software and its Singular Value Decomposition (SVD)-assist functionality (Watermark Numerical Computing, 2004) was used to help update the full set of parameter values and improve the calibration.

3.5 CALIBRATION RESULTS

3.5.1 MODEL PARAMETER MODIFICATIONS

Model calibration consisted of modifying the distribution and magnitude of horizontal hydraulic conductivity, ratio of horizontal to vertical hydraulic conductivity, specific yield, and specific storage values using the pilot point method discussed above. The final distributions of aquifer parameter values for horizontal hydraulic conductivity, vertical anisotropy ratio, specific storage, and specific yield are shown on Figure 12 through Figure 15.

Streambed conductance values for Shirley Canyon and the South Fork of Squaw Creek were included as adjustable parameters in the calibration. The final values obtained from calibration equate to average streambed hydraulic conductivity values of 1.1×10^{-3} feet per day and 1 foot per day. These values are similar to the values of 1.9×10^{-4} feet per day and 1 foot per day that were used in the previous version of the model.

The calibrated value for the fault hydraulic conductivity is 0.16 feet per day, assuming a one-foot thick fault. This value is lower than the surrounding aquifer material and higher than the previously used value of 0.010 feet per day.

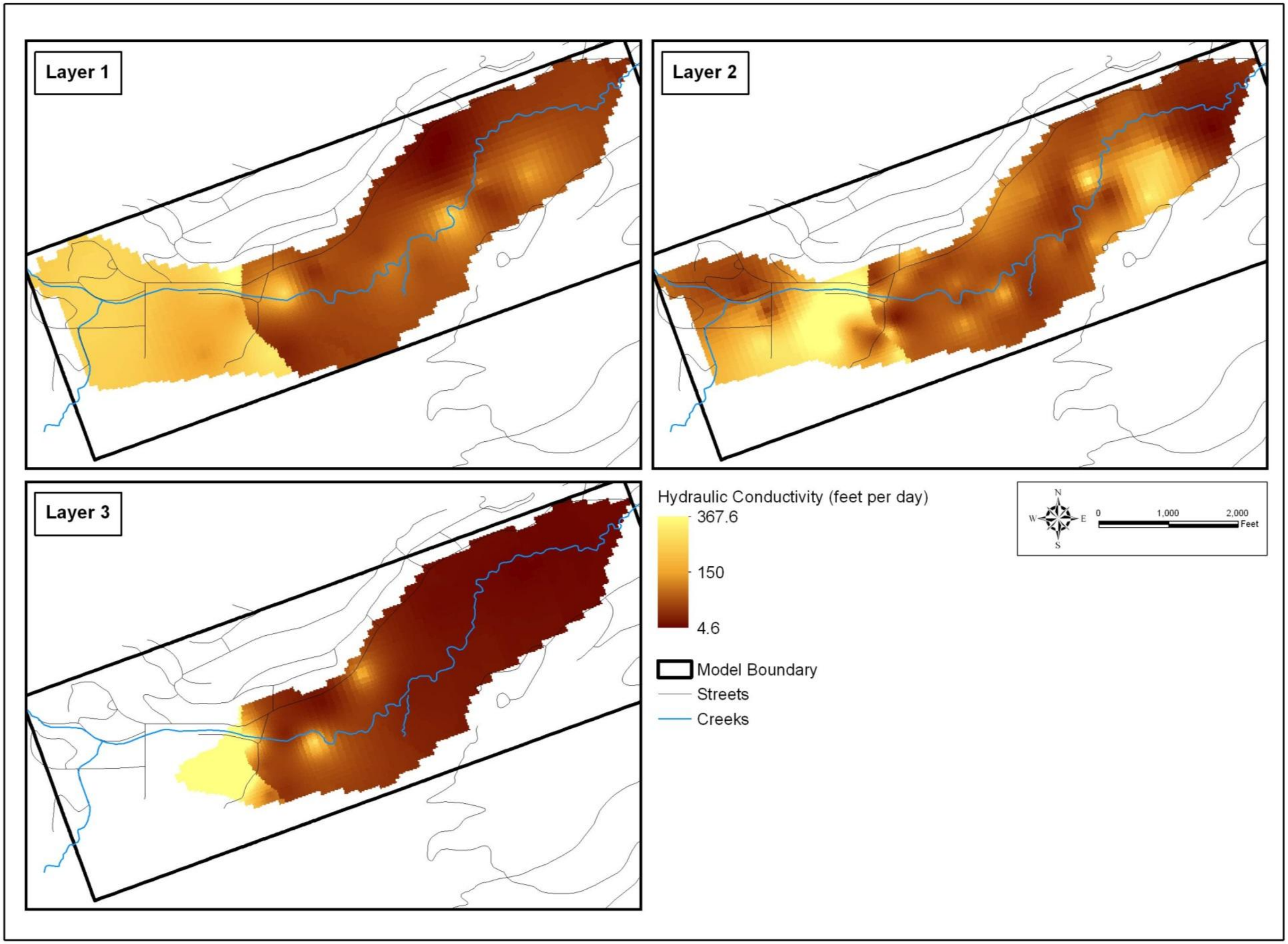


Figure 12: Distribution of Hydraulic Conductivity

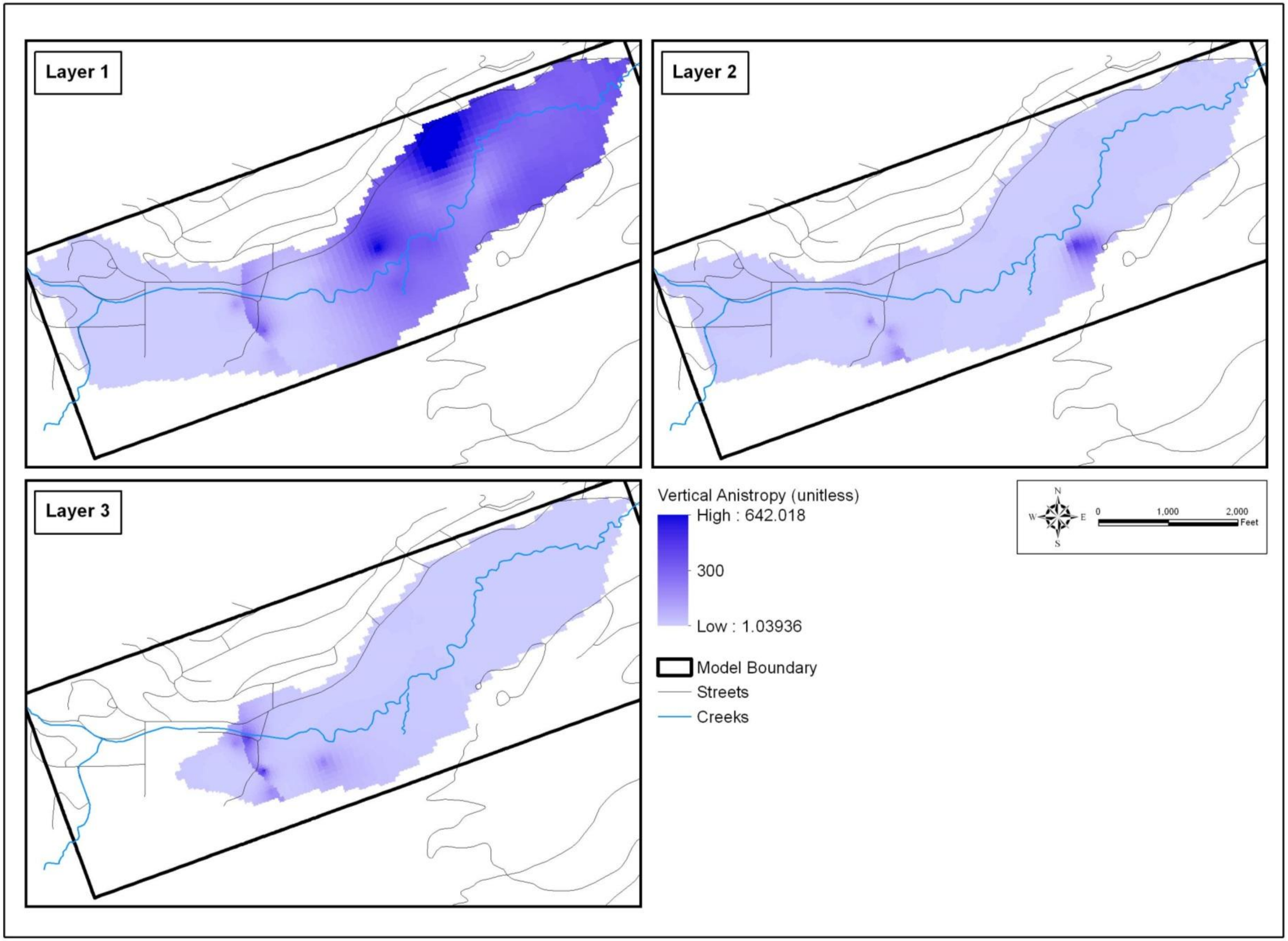
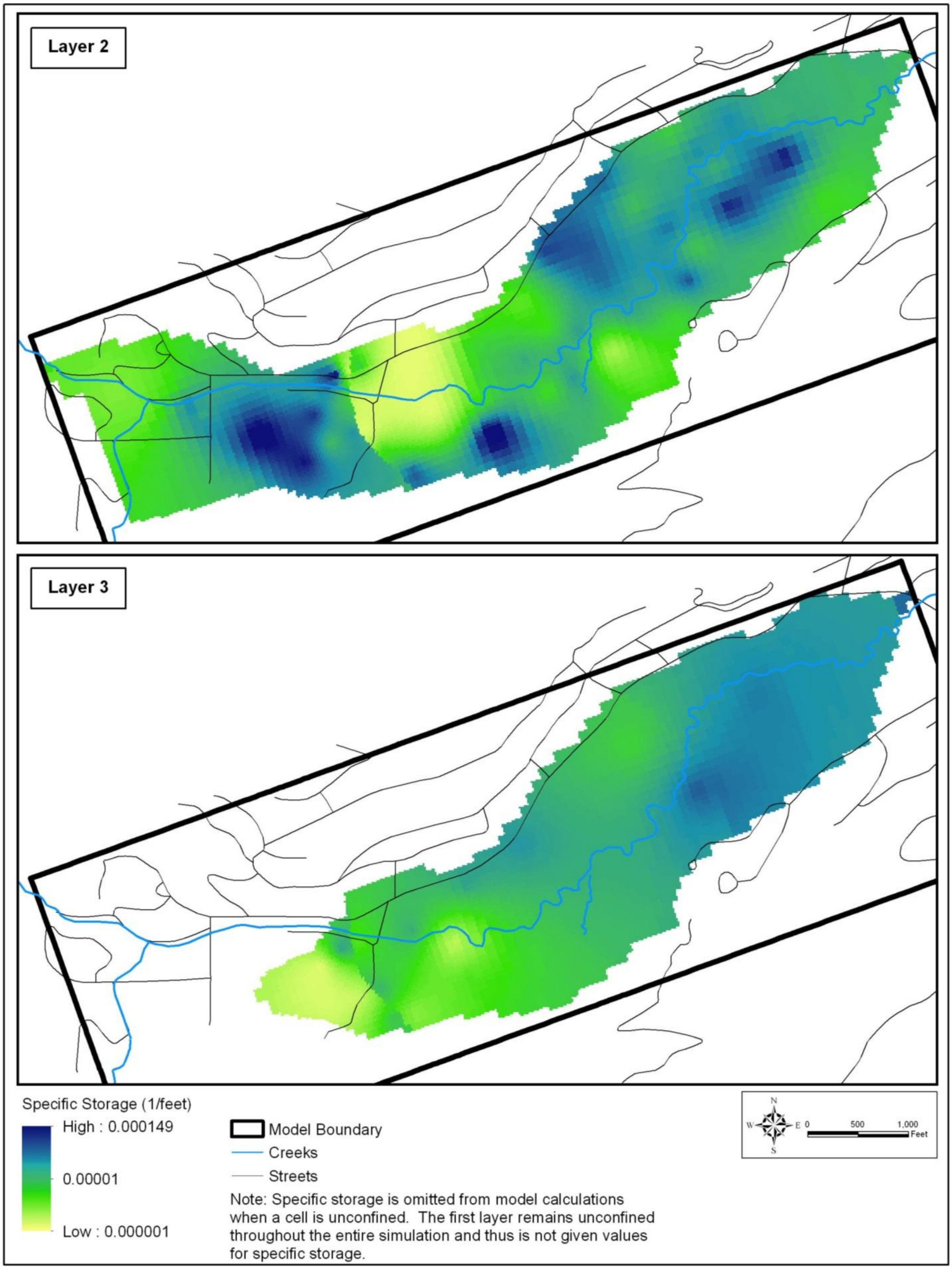


Figure 13: Distribution of Vertical Anisotropy Ratio



Note: Specific storage is omitted from model calculations when a cell is unconfined. The first layer remains unconfined throughout the entire simulation and thus is not given values for specific storage.

Figure 14: Distribution of Specific Storage

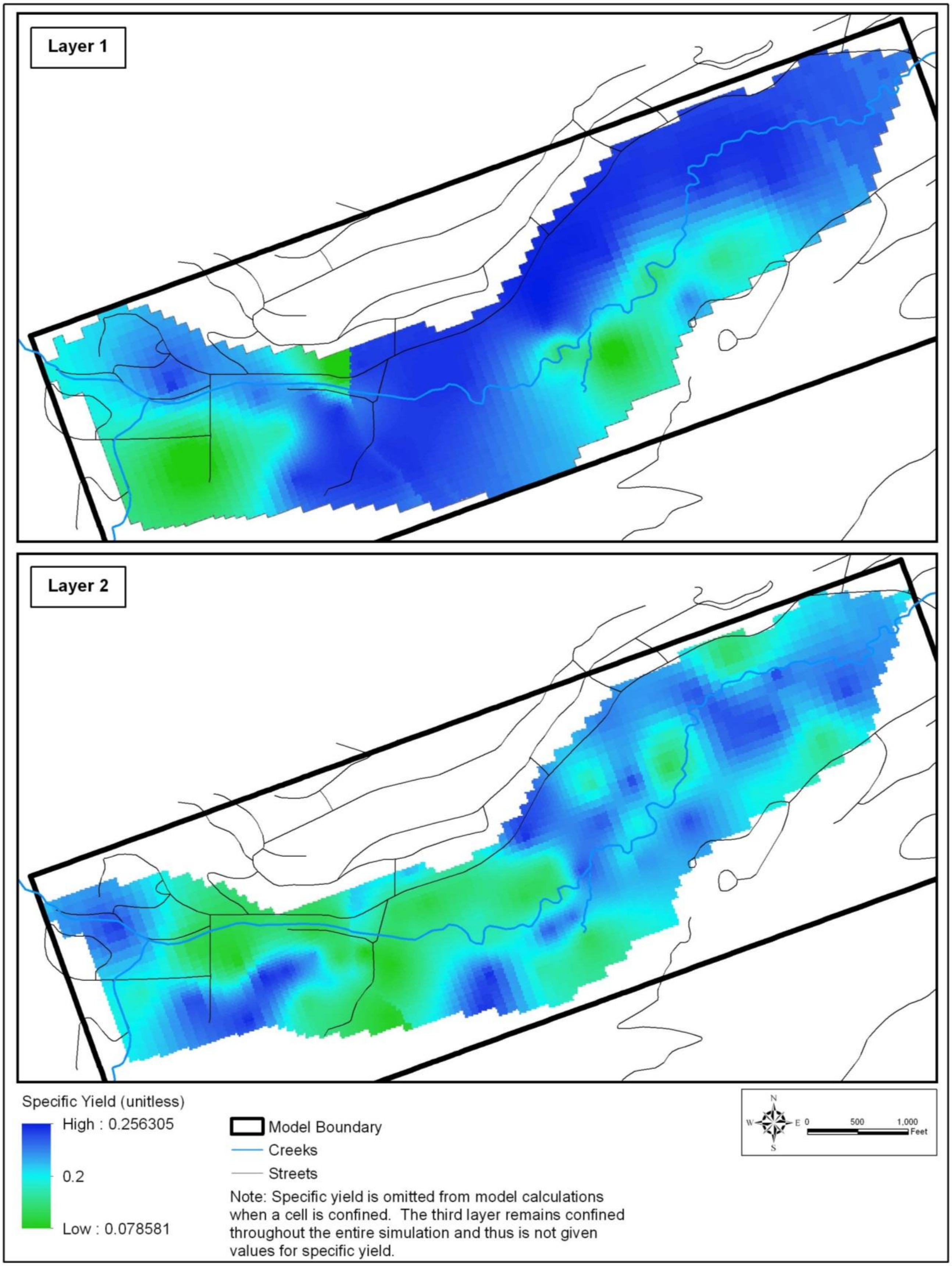


Figure 15: Distribution of Specific Yield

3.5.2 GROUNDWATER ELEVATION CALIBRATION

Flow model calibration is commonly evaluated by comparing simulated groundwater elevations with observed groundwater elevations from monitoring and production wells. Hydrographs of simulated groundwater elevations should generally match the trends and fluctuations observed in measured hydrographs. Furthermore, the average errors between observed and simulated groundwater elevations should be relatively small and unbiased. The well locations used for calibrating the groundwater flow model are shown on Figure 17.

A review of the data collected in the Squaw Valley meadow area revealed that groundwater levels commonly rise above ground surface in the monitoring wells in this area. About one third of the groundwater elevation data collected from monitoring wells in the meadow were above ground. Such conditions indicate local confining layers or strongly upward flow. Both possibilities are plausible, as the meadow is a wetland and natural groundwater discharge area. However, as the modeling objectives are focused on the Western side of Squaw Valley, the model was not designed with features capable of reproducing either of these complex phenomena. As a result, all groundwater level targets that were above ground surface were given no weight in the calibration, and the model results are not expected to accurately match these above-ground elevations.

A review of the groundwater elevation data also revealed an apparent inconsistency in the groundwater levels measured in well SVPSD-5R. This well is in close proximity to monitoring wells SVPSD-5S, SVPSD-5D, and SVMWC-1. Comparing groundwater levels from well SVPSD-5R with groundwater levels from the three nearby wells revealed that the levels in well SVPSD-5R appear to be anomalously high. A side by side comparison of wells SVPSD-5R and SVPSD-5D is presented on Figure 16. In order to prevent the calibration from producing extreme local variations in hydraulic property values around these wells, the influence of SVPSD-5R was reduced. The weight of observation targets taken from SVPSD-5R were reduced but not entirely eliminated.

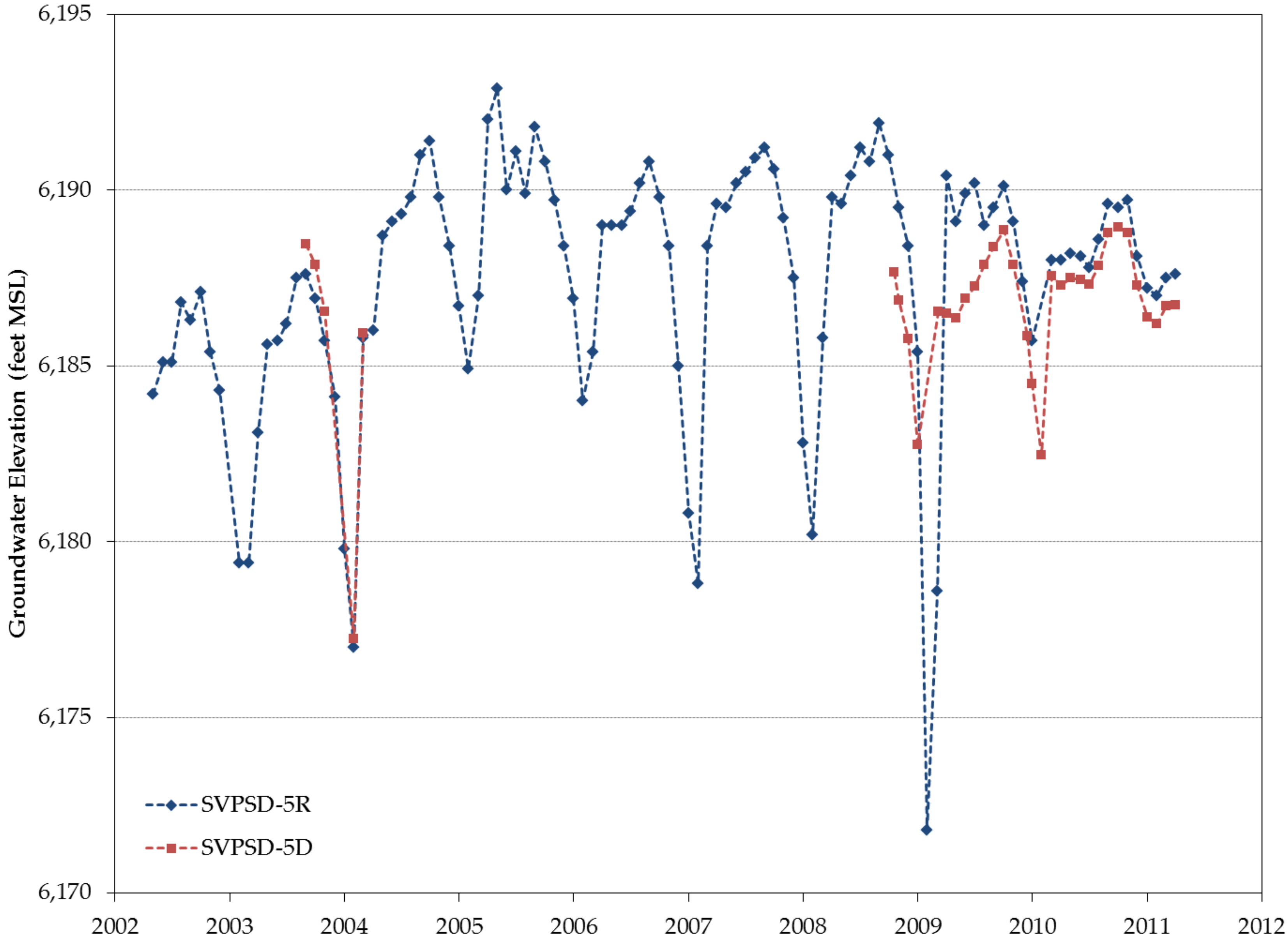
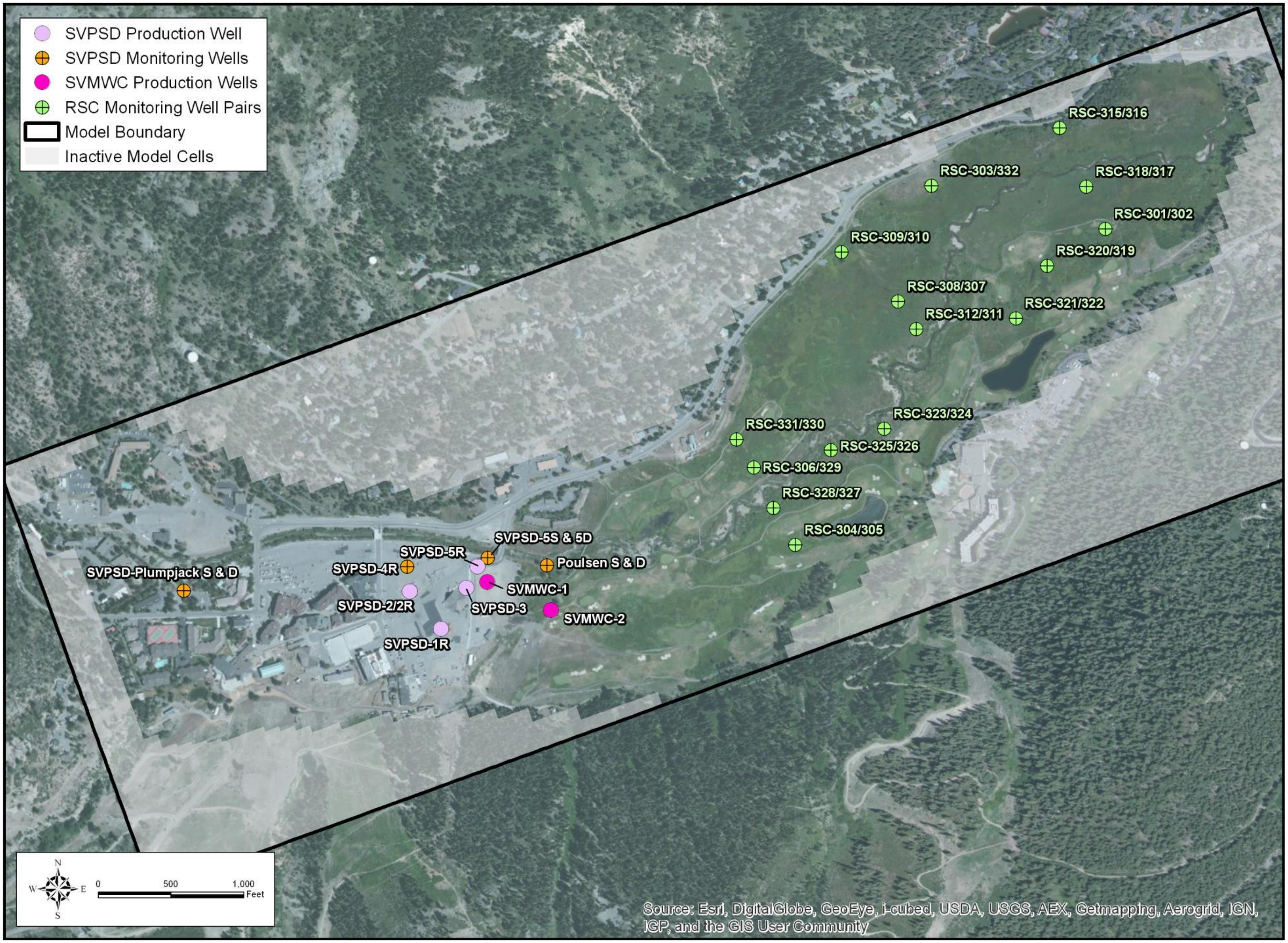


Figure 16: Observed Groundwater Elevations in Wells SVPSD-5R and SVPSD-5D



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

Figure 17: Target Well Locations

Example hydrographs showing both observed and simulated groundwater elevations from the calibrated model are shown on Figure 18 through Figure 20. These example hydrographs were chosen to demonstrate the model's accuracy in different parts of Squaw Valley. The hydrographs show that the model accurately simulates the mean groundwater levels and the magnitude of groundwater fluctuations for the Western side of the basin. The hydrographs from the Eastern side of the basin show that the model does not simulate groundwater levels above ground surface, as discussed earlier. Groundwater levels above ground surface were not included in the calibration but were presented in every hydrograph. A complete set of hydrographs showing both observed and simulated groundwater elevations are included in APPENDIX A:.

Various graphical and statistical methods can be used to demonstrate the magnitude and potential bias of the calibration errors. Figure 21 shows all simulated groundwater elevations plotted against observed groundwater elevations for all stress periods in the calibration. Results from an unbiased model will scatter around a 45° line on this graph. If the model has a bias such as exaggerating or underestimating groundwater levels, the results will diverge from this 45° line. Figure 21 demonstrates that the results tend to lie close, but slightly below, a 45° line. This suggests that model has a minor bias towards underestimating average groundwater levels. This is likely due to the fact that the model cannot simulate the measured groundwater elevations that are above ground surface in the meadow area.

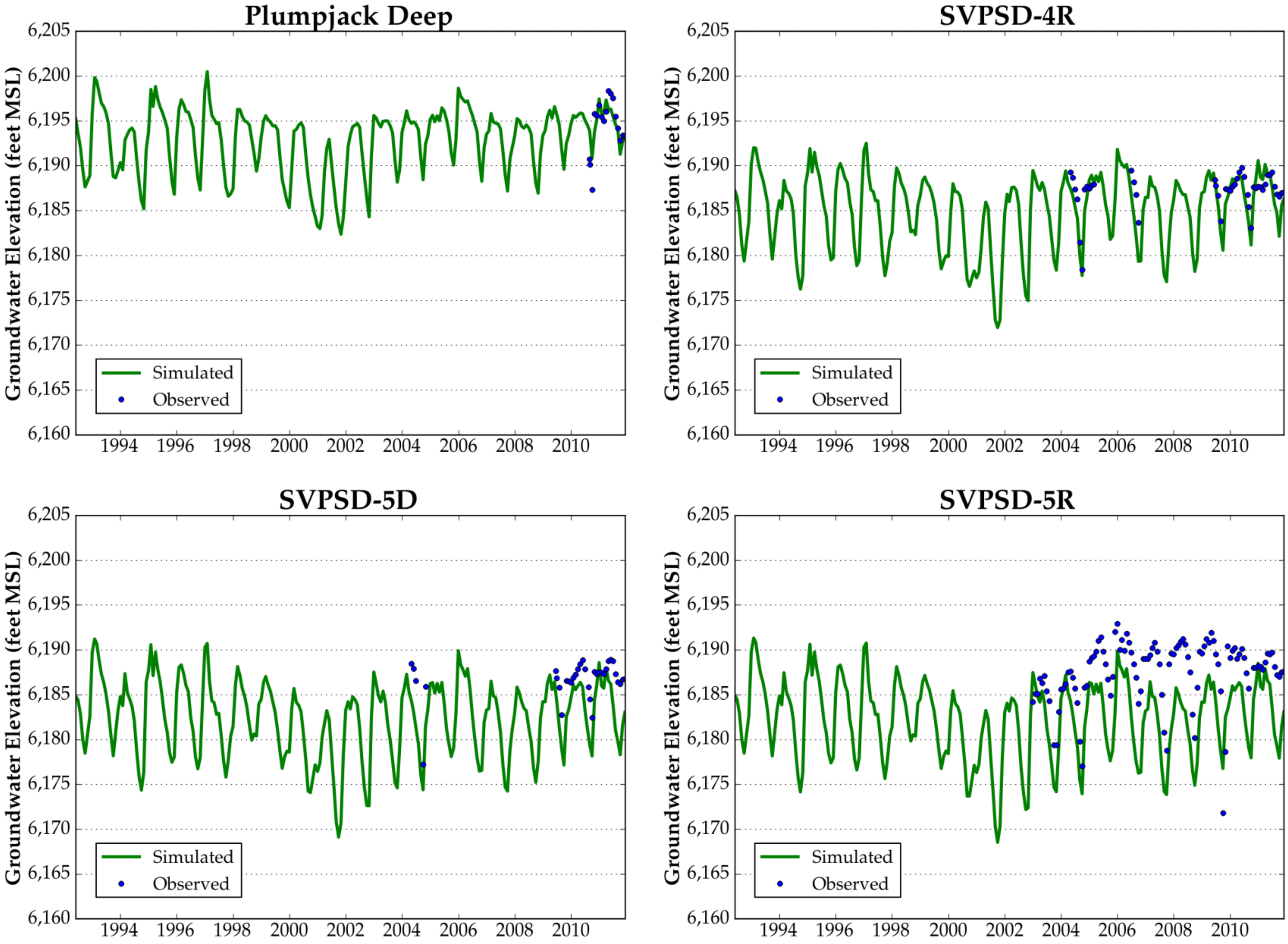


Figure 18: Calibration Hydrographs – Western Valley

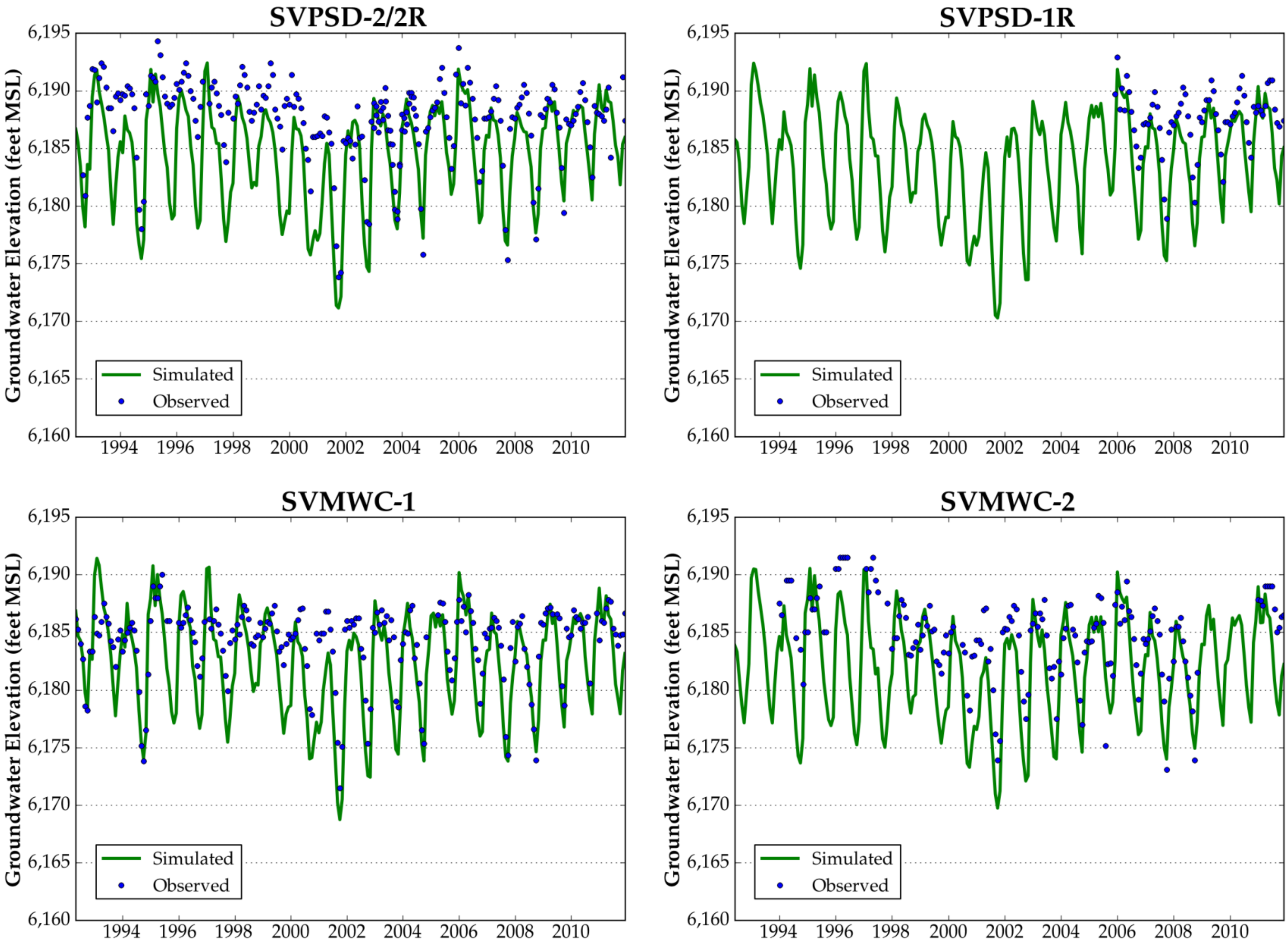


Figure 19: Calibration Hydrographs – Western Valley

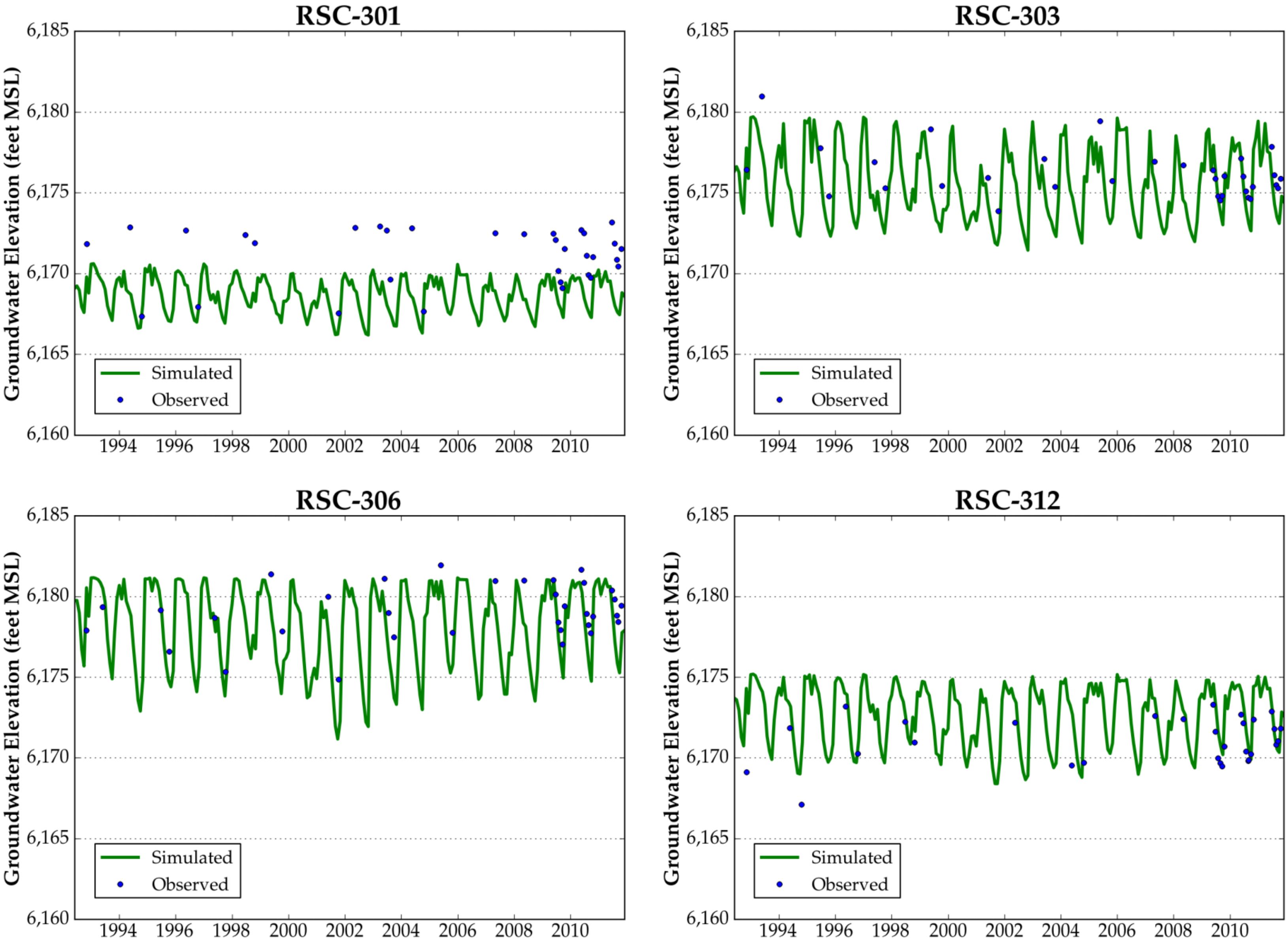


Figure 20: Calibration Hydrographs - Meadow

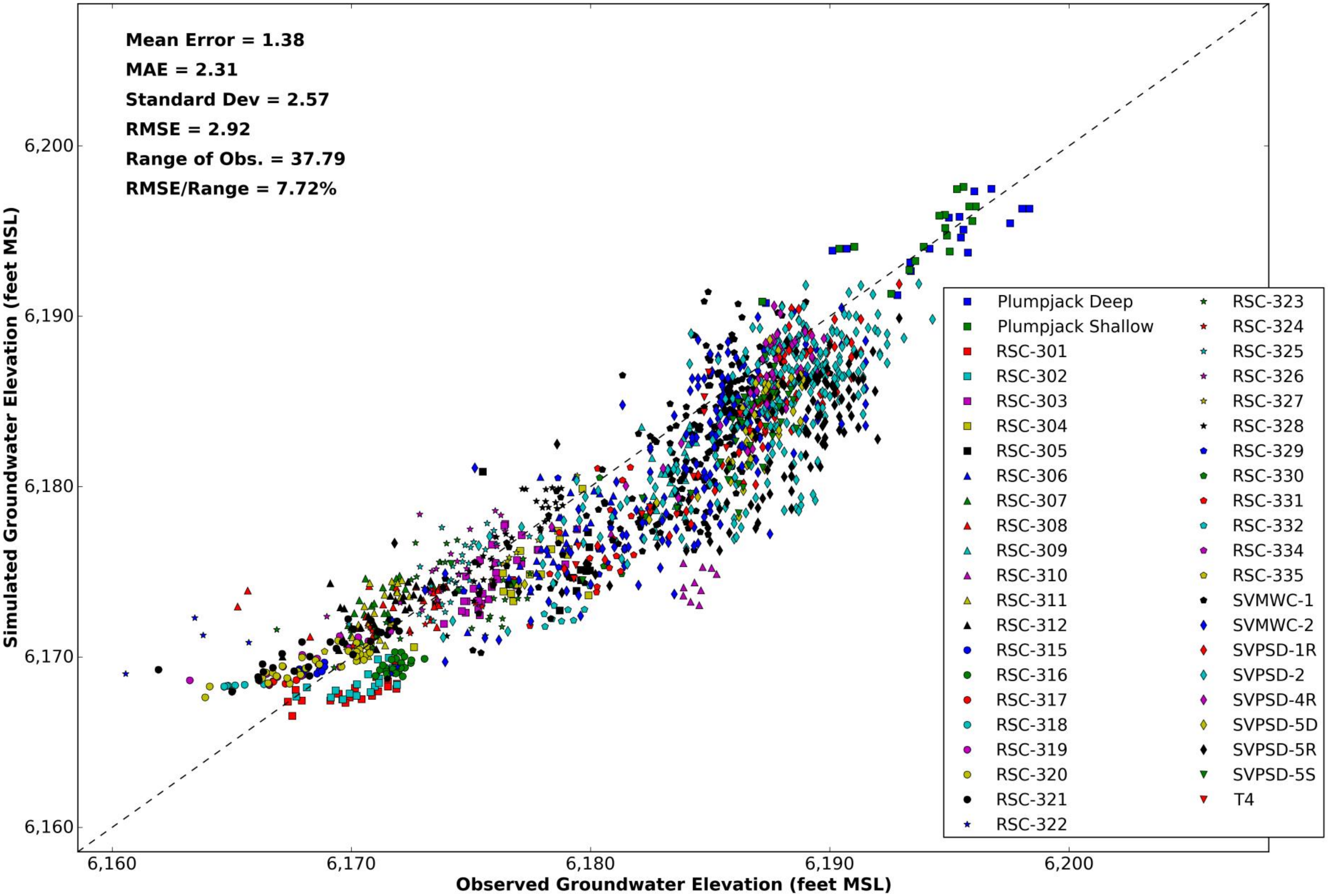


Figure 21: Simulated Versus Observed Groundwater Elevations

Figure 21 also includes various statistical measures of calibration accuracy. The four statistical measures used to evaluate calibration are the mean error (ME), the mean absolute error (MAE), the standard deviation of the errors (STD), and the root mean squared error (RMSE). Each of these statistical measures was calculated using weighted measurements, where all weights have been normalized such that the sum of all weights is equal to one.

The mean error is the average error between measured and simulated groundwater elevations for all data on Figure 21.

$$ME = \sum_{i=1}^{n} w_i \left(h_m - h_s\right)_i$$

Where h_m is the measured groundwater elevation, h_s is the simulated groundwater elevation, w_i is the normalized observation weight and n is the number of observations.

The mean absolute error is the average of the absolute differences between measured and simulated groundwater elevations.

$$MAE = \sum_{i=1}^{n} w_i \left|h_m - h_s\right|_i$$

The standard deviation of the errors is one measure of the spread of the errors around the 45º line on Figure 21. The population standard deviation is used for these calculations

$$STD = \sqrt{\sum_{i=1}^{n} w_i \left(h_m - h_s\right)_i^2 - \left(\sum_{i=1}^{n} w_i \left(h_m - h_s\right)_i\right)^2}$$

The RMSE is similar to the standard deviation of the error. It also measures the spread of the errors around the 45º line on Figure 21, and is calculated as the square root of the average squared errors.

$$RMSE = \sqrt{\sum_{i=1}^{n} w_i \left(h_m - h_s\right)_i^2}$$

As a measure of successful model calibration, Anderson and Woessner (1992) state that the ratio of the spread of the errors to the total head range in the system should be small to ensure that the errors are only a small part of the overall model response. As a general rule, the RMSE should be less than 10% of the total head range in the model. The RMSE of 2.92, shown on Figure 21, is approximately 7.72% of the total head range of 37.8 feet. A second general rule that is occasionally used is that the mean error should be less than 5% of the total head range in the model. The mean error of 1.38 is approximately 3.65% of the total head range. Therefore, on average, the model errors are within an acceptable range.

A second graph used to evaluate bias in model results is shown on Figure 22. This figure is a graph of observed groundwater elevations versus model residual (simulated elevation minus observed elevation). Results from a non-biased simulation will appear as a cloud of data points clustered around the zero model residual line. Results that do not cluster around the zero residual line show potential model bias. Results that display a trend instead of a random cloud of points may suggest additional model bias. The results plotted on Figure 22 show that the calibrated model results have a minor bias towards underestimating high observed groundwater elevations.

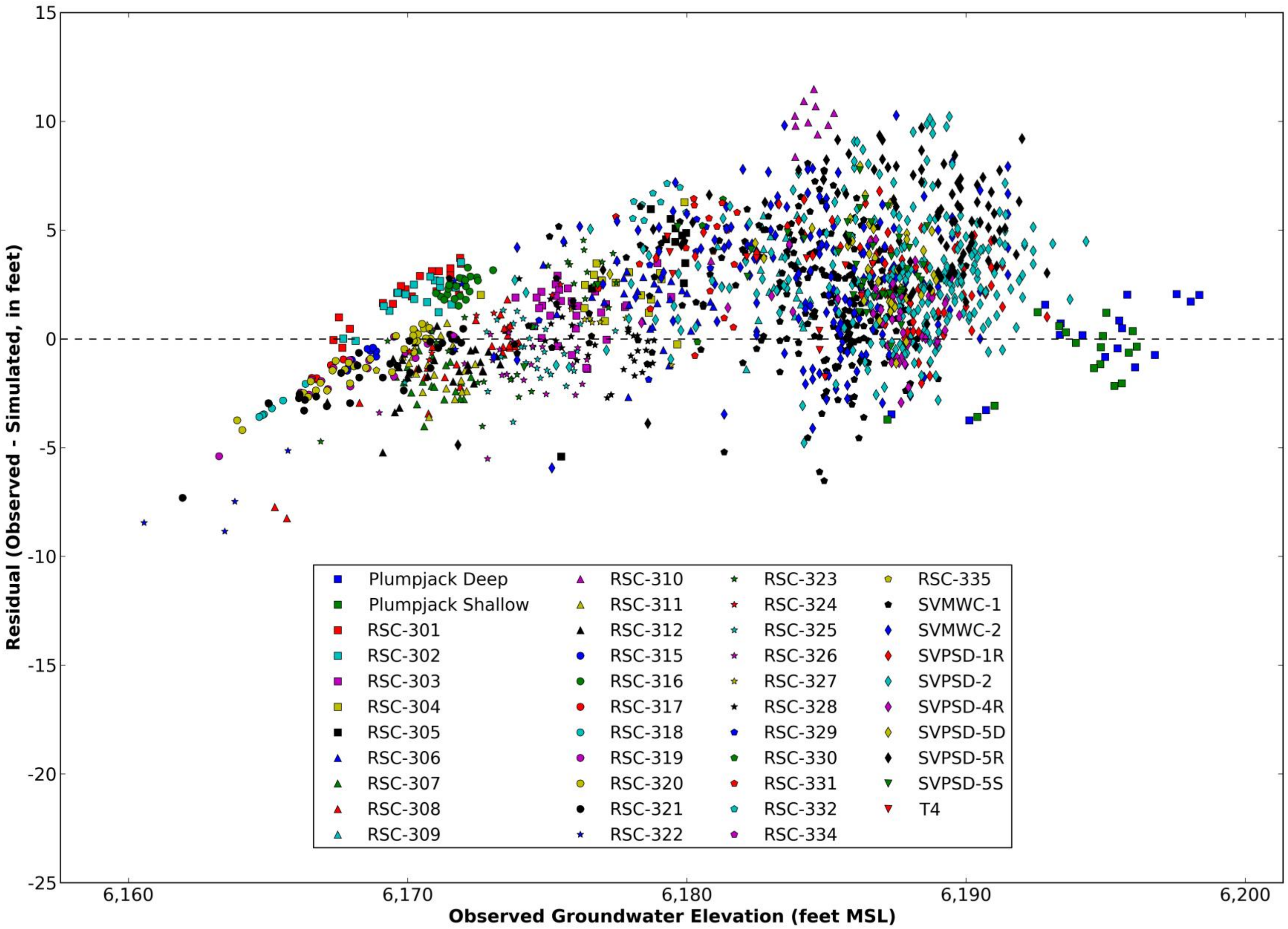


Figure 22: Observed Groundwater Elevations versus Model Residual

3.5.3 STREAMBED FLUX

Water flow into and out of the aquifer through the streambed were not formally included as observations in the calibration. Instead, the simulated flow rates were manually compared to estimates from two separate studies. A previous study (HydroMetrics WRI, 2013) using thermal probes to estimate seepage velocities estimated that seepage in the trapezoidal channel ranged between an upward flow of 0.28 feet per day to a downward flow of 1.11 feet per day during the early and late summer months.

Figure 23 compares the modeled seasonal behavior of streambed seepage to field measurements. The vertical axis shows the rate of streambed seepage in feet per day, with positive numbers signifying inflow from the aquifer to the stream and negative numbers signifying seepage loss from the stream to the aquifer. The blue line represents the average monthly simulated seepage in the trapezoidal channel. The green bars show the range of inflow rates measured in 2009. Two sets of measurements were collected, one between May and June 2009, and one between October and November 2009. The simulated seepage represented by the blue line lies within the range of the measured seepages, shown by the green bars. This shows that the simulated seepage rates compare well to rates measured during the May to June period and the October to November period.

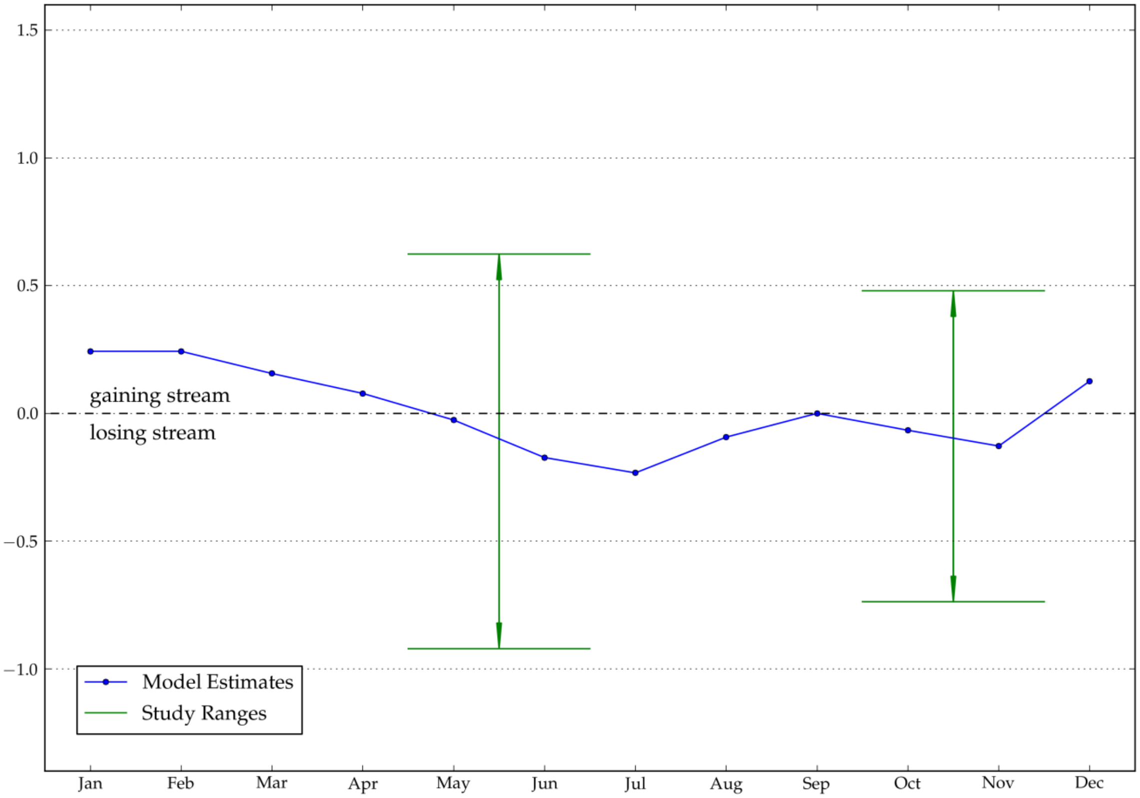


Figure 23: Comparison of Modeled and Measured Rates of Streambed Seepage for the Trapezoidal Channel Segment of Squaw Creek

A study by Jean Moran from Cal State East Bay and Lawrence Livermore National Laboratory (LLNL) (Moran, 2013) used Radon as a tracer to estimate stream seepage rates in the meadow area during summer months. She estimated average upward seepage rates of between 0.8 and 1.1 feet per day during the summer months. One caveat to this tracer study is that it is only capable of detecting additions of water to the stream from the aquifer, but not losses from the stream to the aquifer. As a result, the tracer study should be considered maximum values that would occur if no losses took place.

Figure 24 compares simulated upward streambed seepage in the meadow to the field measurements collected by Jean Moran. The vertical axis shows the rate of streambed seepage in feet per day. The blue line represents the average monthly simulated seepage in the meadow. This average comprises only the average monthly rates of inflow to the stream: outflow from the stream to the aquifer was not included in these calculations. The green bars between May and June show the range of inflow rates that were measured in the field.

The simulated Squaw Creek inflow values in the meadow are below the range of measured values throughout the entire season. As was previously discussed, the model does not include features that allow it to recreate some of the very high water levels observed in shallow wells beneath the meadow. As a result, the upward gradients simulated by the model in this region are not as strong as those that are likely to exist in the real aquifer. When upward gradients are present beneath the stream they act to drive water from the aquifer into the stream. Therefore, the model's underestimation of upward gradients in the meadow is likely the cause of its corresponding underestimation of seepage rates into Squaw Creek.

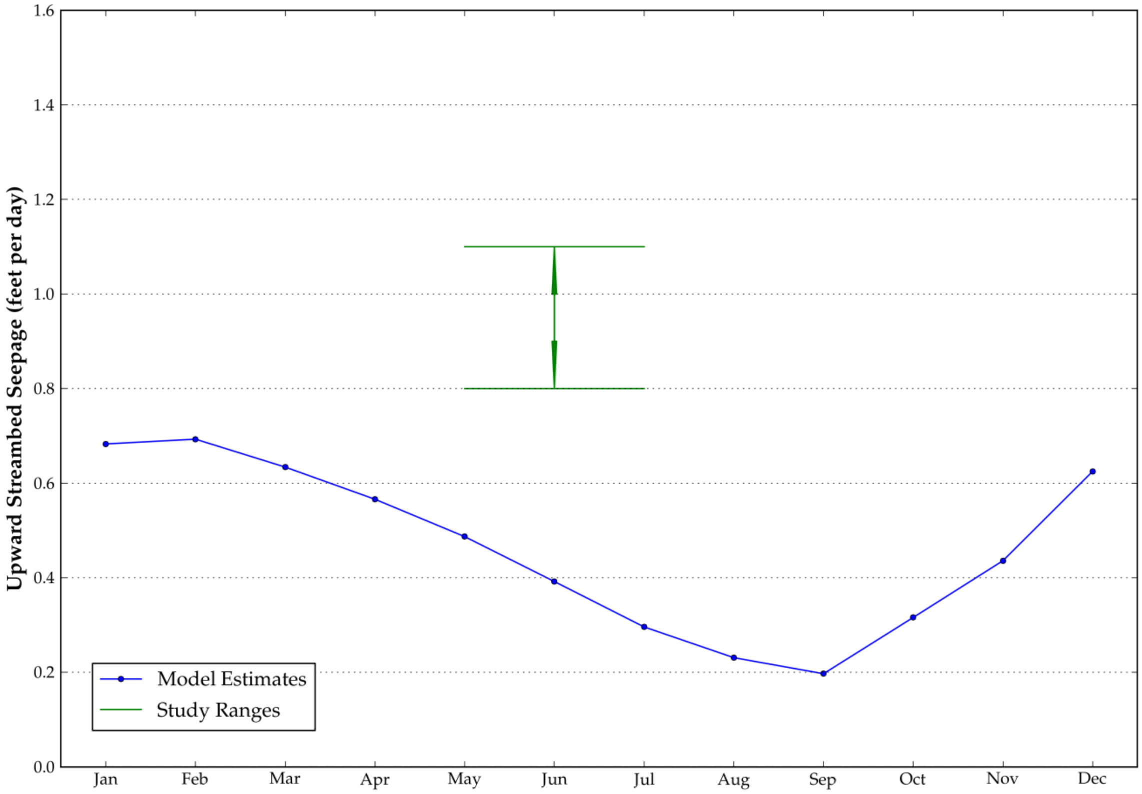


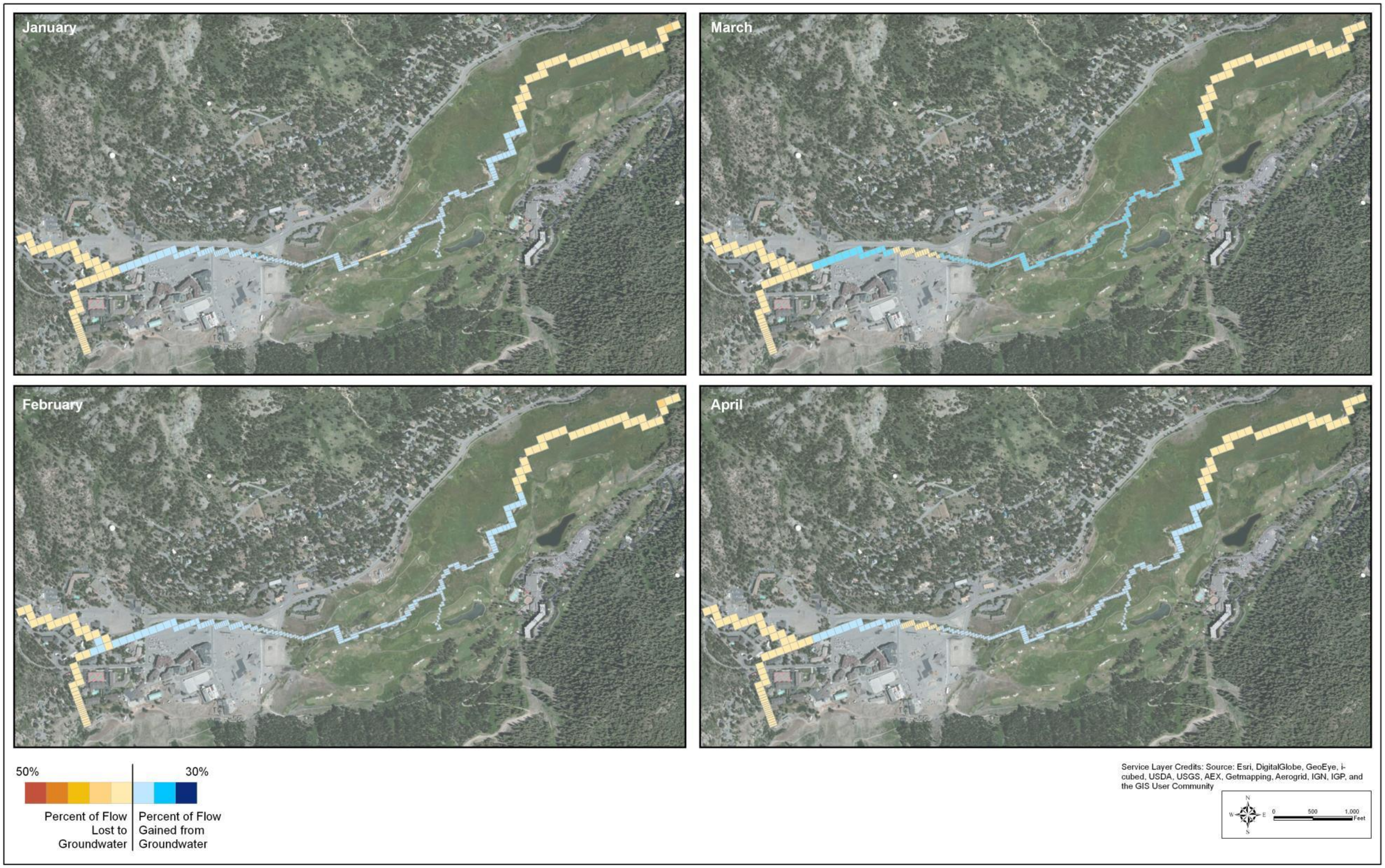
Figure 24: Comparison of Modeled and Measured Rates of Upward Streambed Seepage for the Meadow Segment of Squaw Creek

Further analysis was conducted to capture the seasonal behavior of the stream/aquifer interaction at every model cell along Squaw Creek. For each model cell, the volume of water gained from the aquifer or lost to the aquifer was compared to the volume of water flowing through the stream. This comparison was expressed in two different ways, depending on whether the stream was gaining or losing. For gaining portions of the stream, the interaction of stream and aquifer is expressed as the percent of outgoing streamflow that was gained from the aquifer. For losing portions of the stream, the interaction of stream and aquifer is expressed as the percent of incoming streamflow that is lost to the aquifer. From these percentages monthly values were averaged over every year of the simulation to obtain a view of the average seasonal behavior of stream/aquifer interaction.

Figure 25 through Figure 27 display the seasonal results for each month of an average calendar year. Cells that are colored blue are gaining water from the aquifer for the average month, while cells that are colored yellow and orange are losing water to the aquifer for the average month. In addition, for the month of September, some cells are colored white to signify portions of the stream that are dry for every September of the simulation. This behavior is only seen for the month of September.

A notable observation made from these results is that there are several segments of the stream that display consistent behavior throughout the season. The Shirley Canyon, South Branch of Squaw Creek, and the furthest downstream segments of the stream are all losing (or dry) throughout the entire season. The central meadow and the segment immediately below the parking lot are gaining throughout the entire season. The other portions of the creek, including the trapezoidal channel and a portion through the western side of the meadow, have varying behavior throughout the season. These segments tend to be gaining during the wet season and losing during the dry season.

In general, higher percentages of streamflow are gained from the aquifer and lost to the aquifer during the dry season than during the wet season. These percentage values are higher because streamflows diminish much more than seepage values during the dry season. While this result is not surprising, the figures highlight the idea that stream aquifer interactions are a more important consideration during the periods of low streamflow than during periods of high streamflow.



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

Figure 25: Average Stream/Aquifer Interaction - January through April

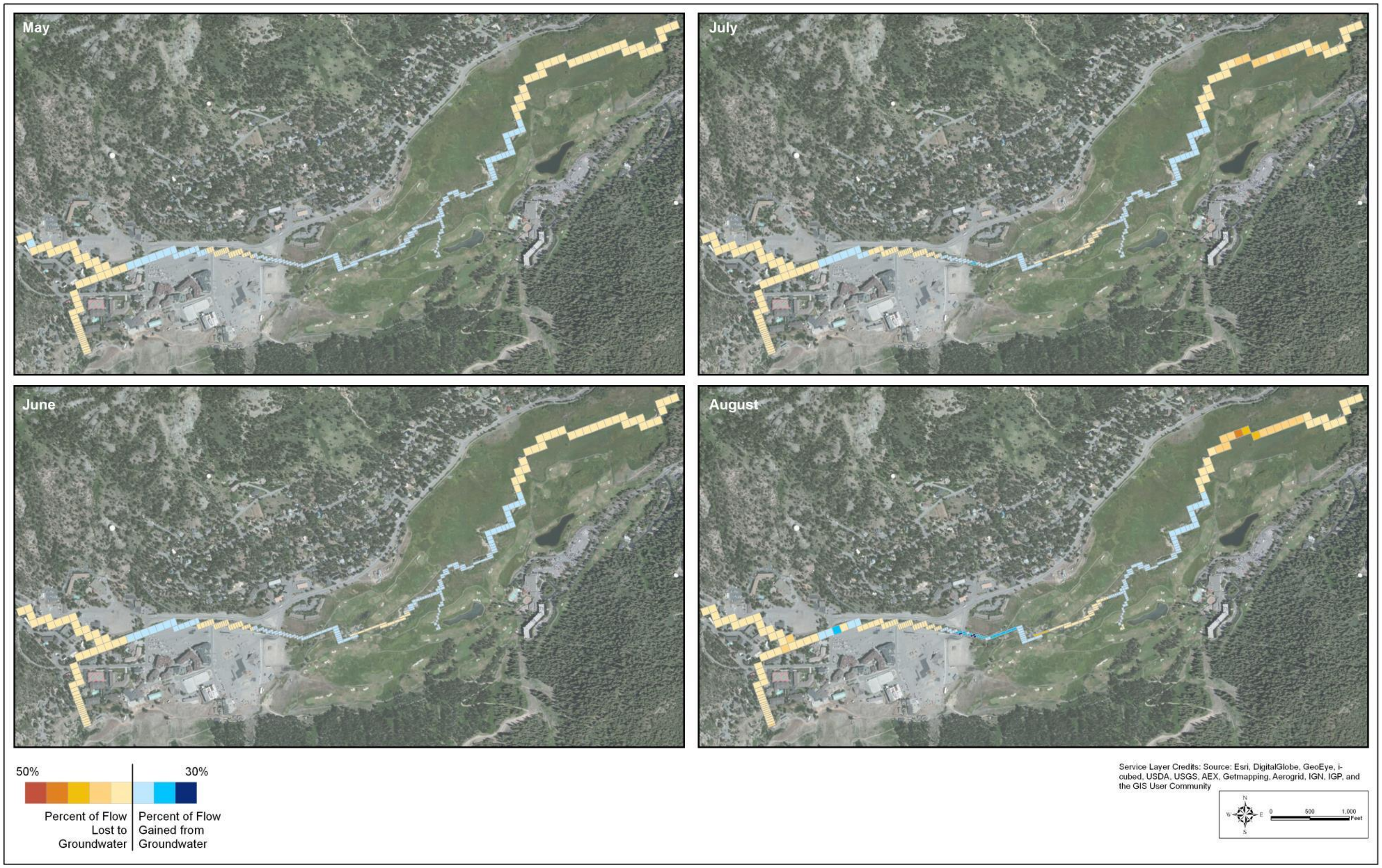


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Figure 26: Average Stream/Aquifer Interaction - May through August

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Figure 27: Average Stream/Aquifer Interaction - September through December

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SECTION 4
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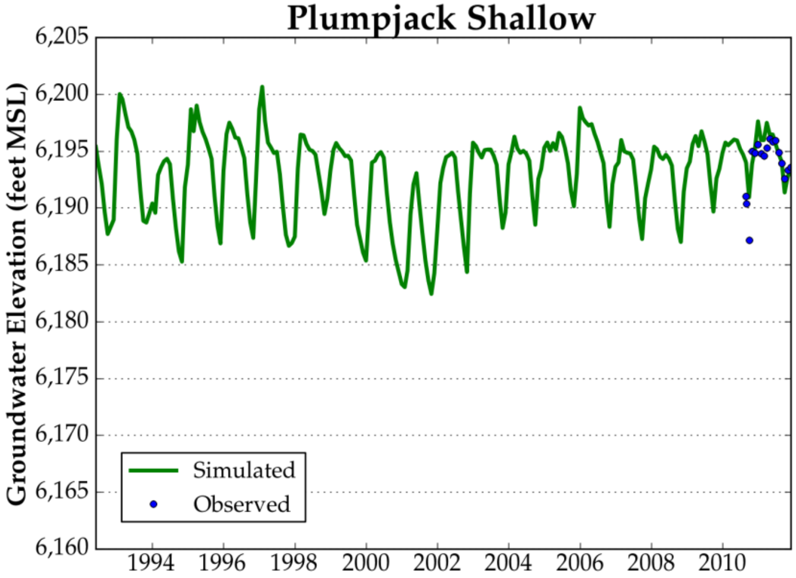
APPENDIX A: HYDROGRAPHS



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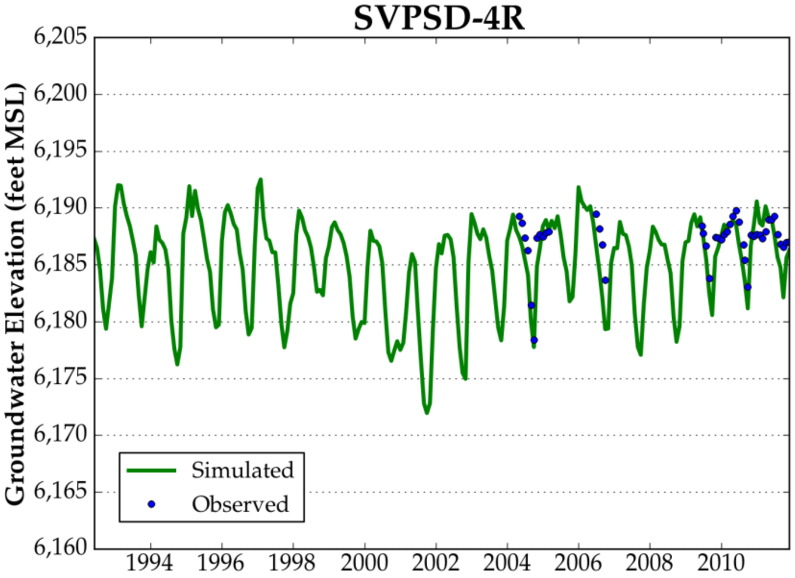

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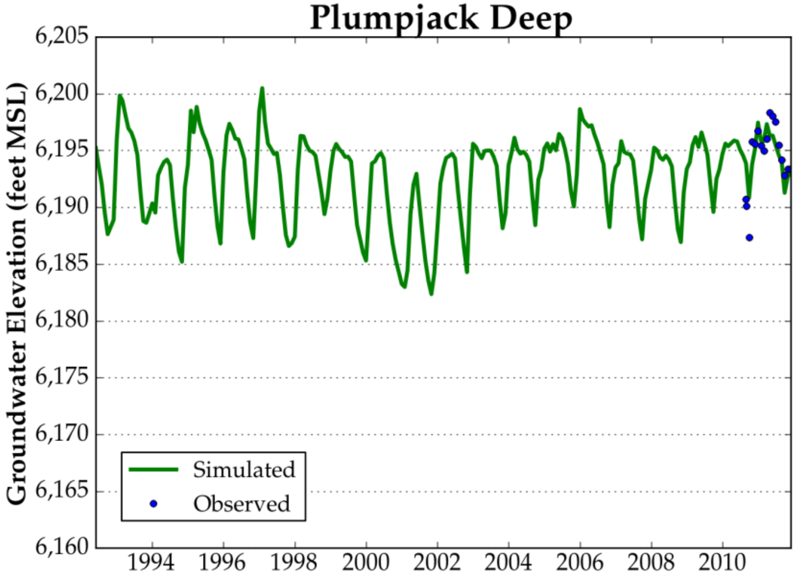

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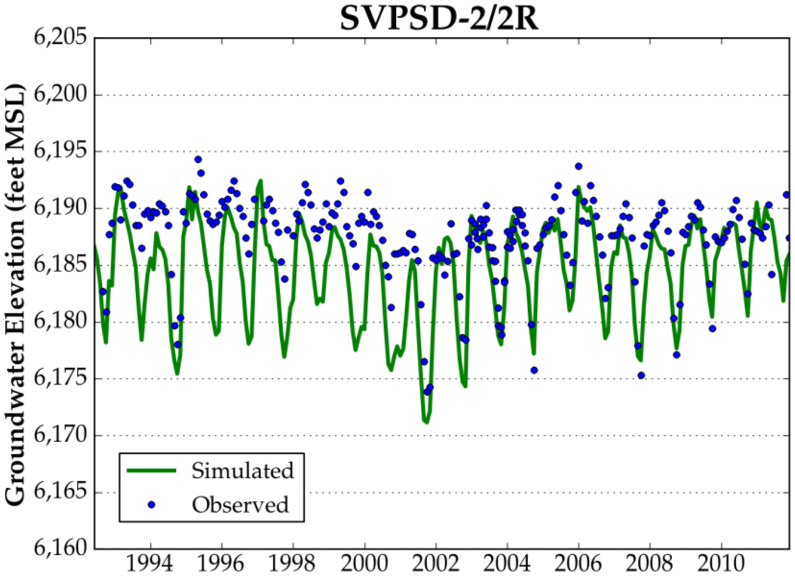

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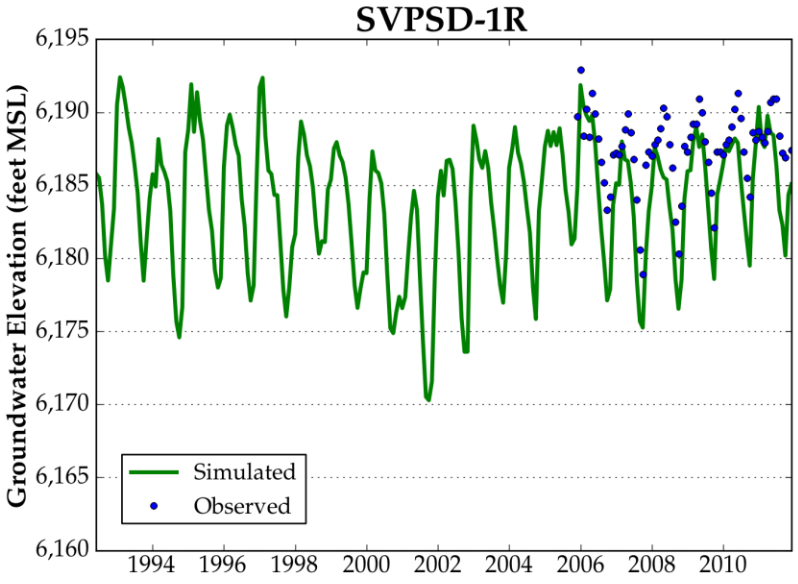
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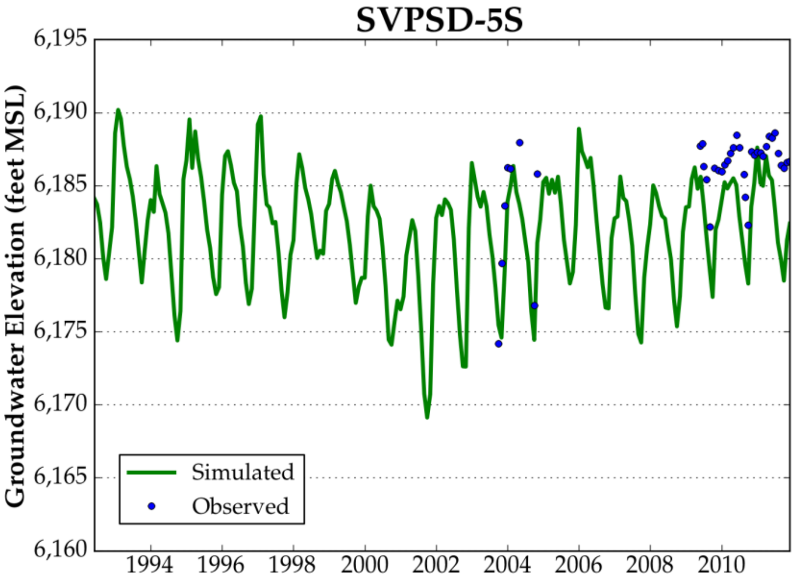
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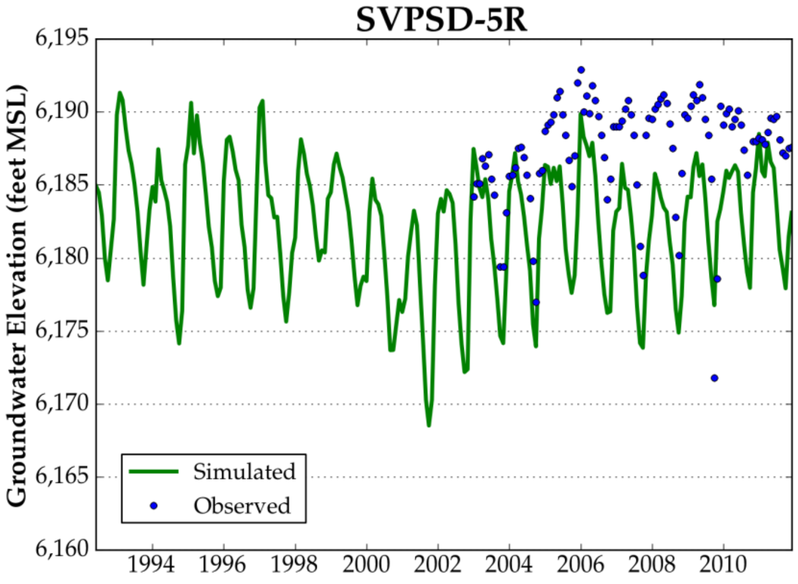
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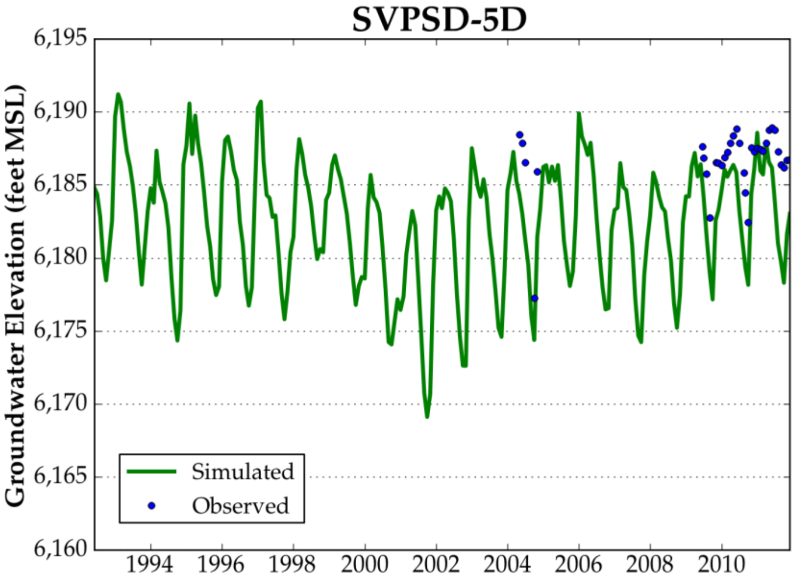
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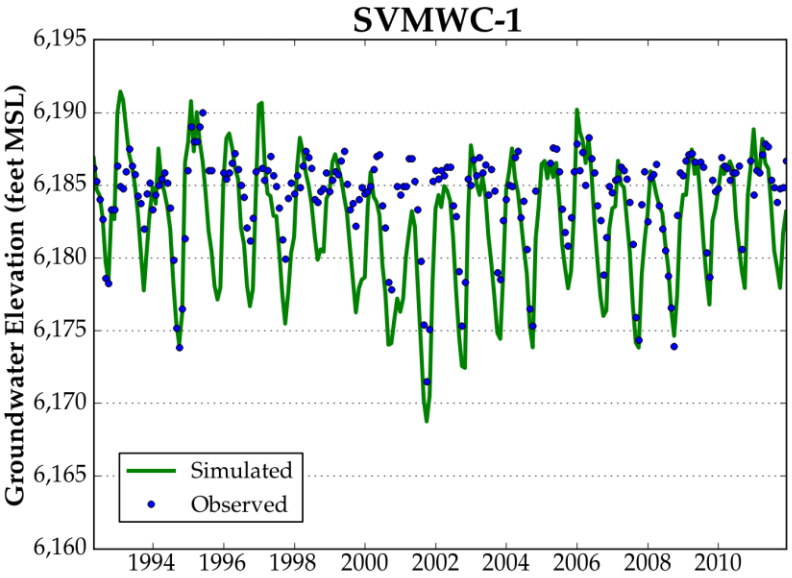
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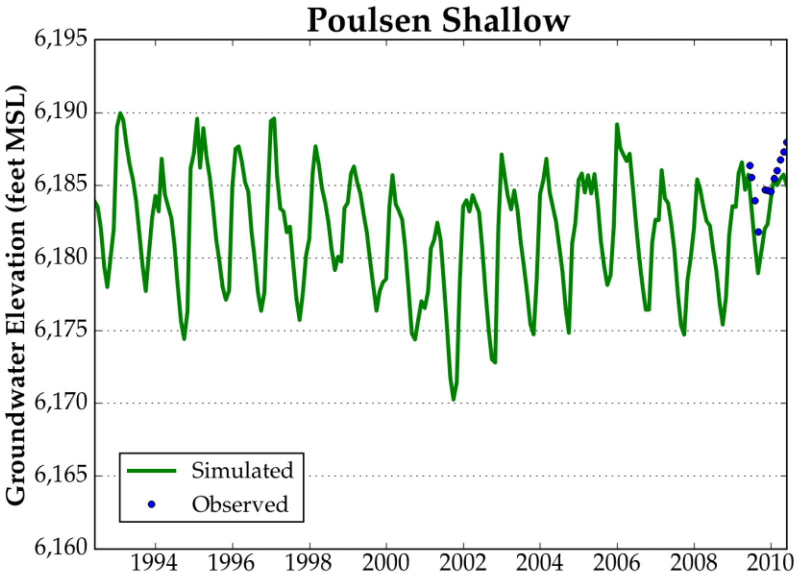
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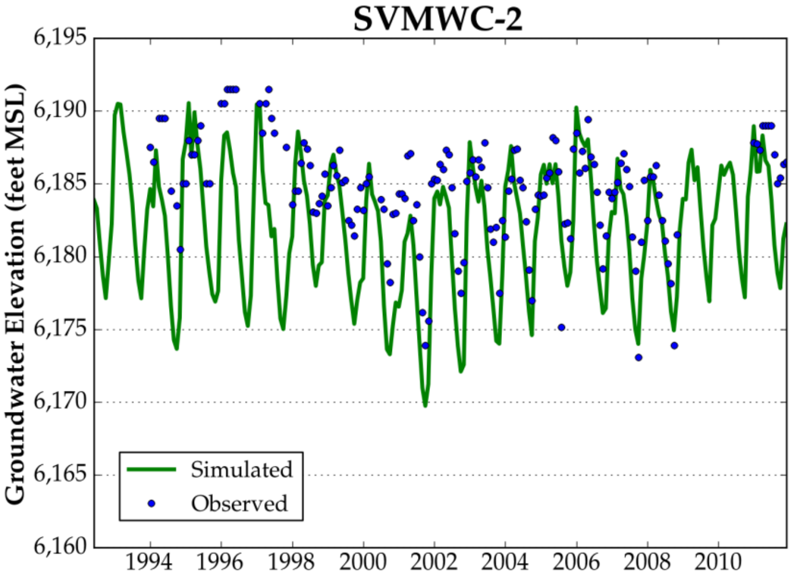
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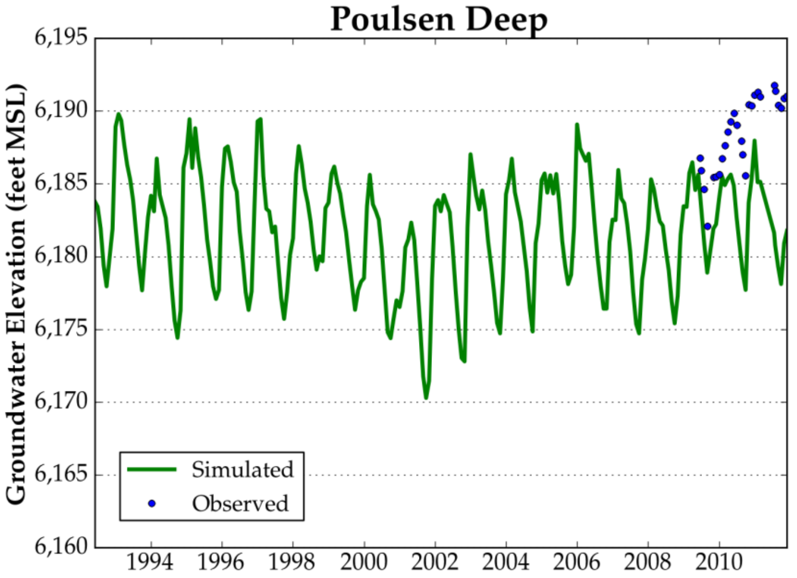
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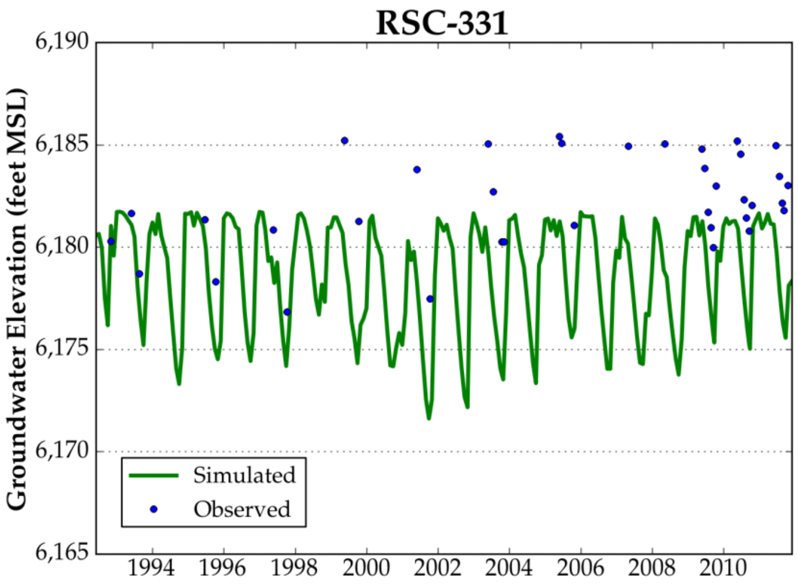
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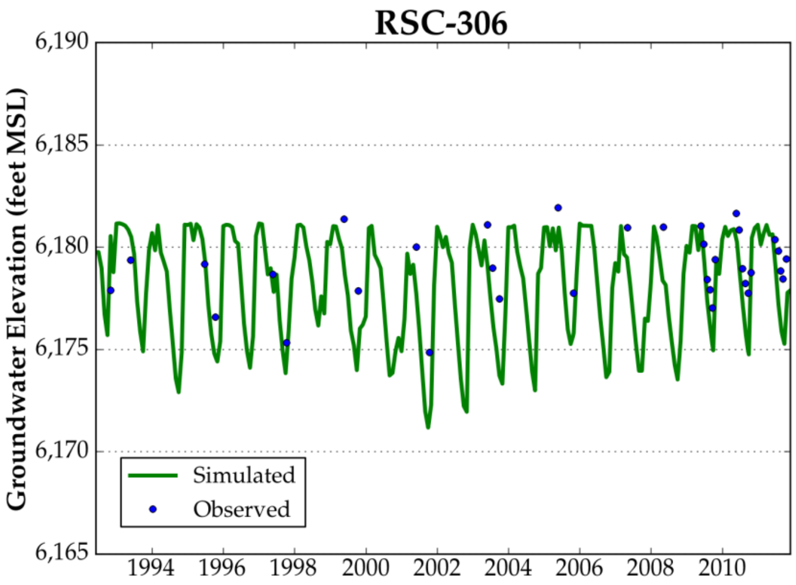
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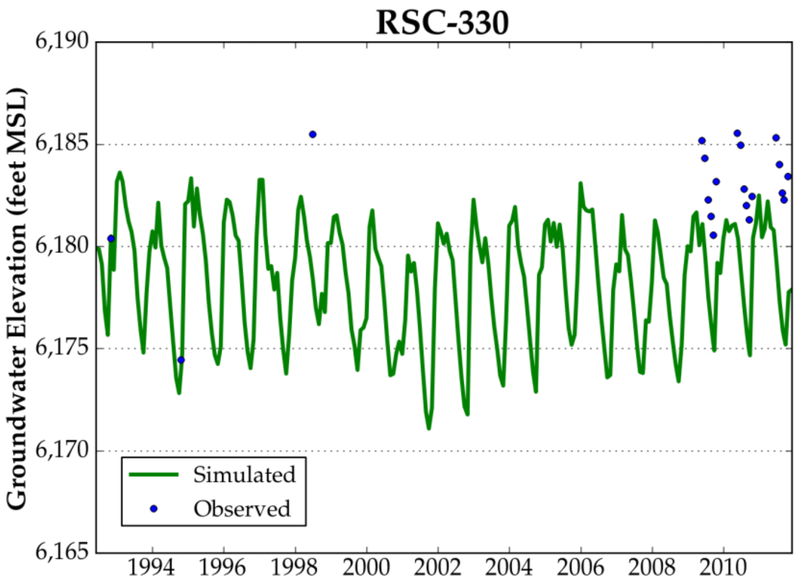
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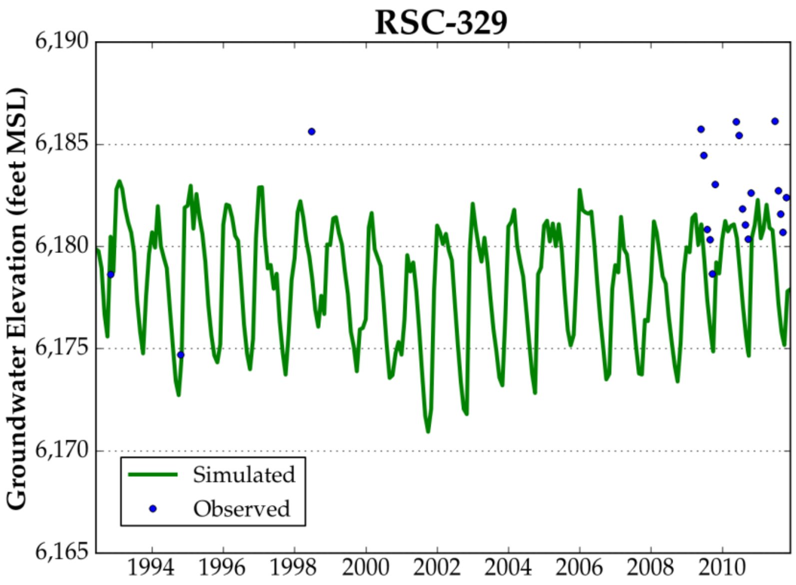
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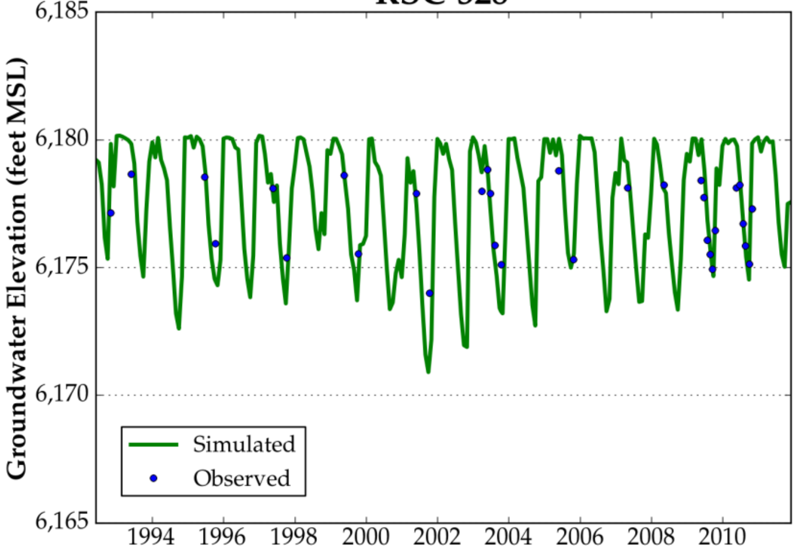

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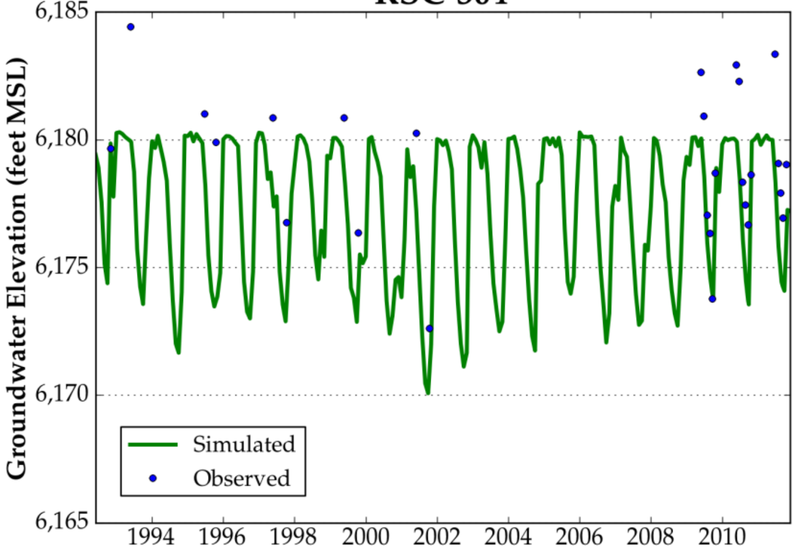

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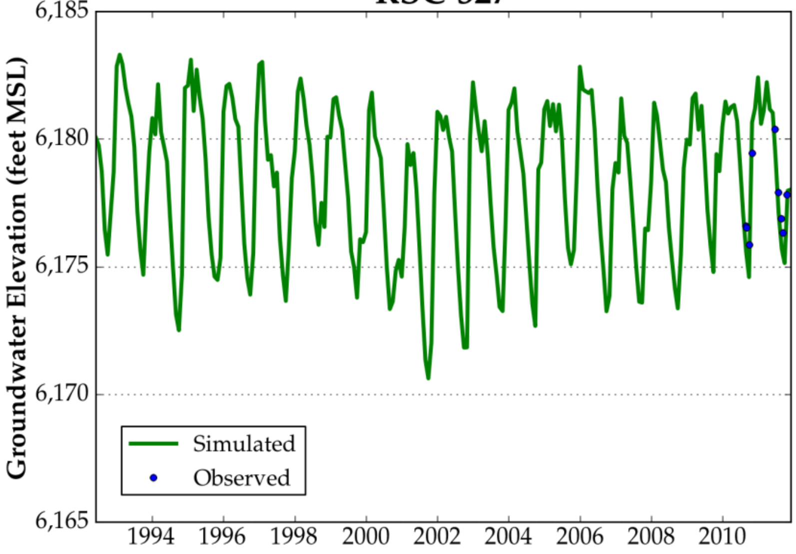

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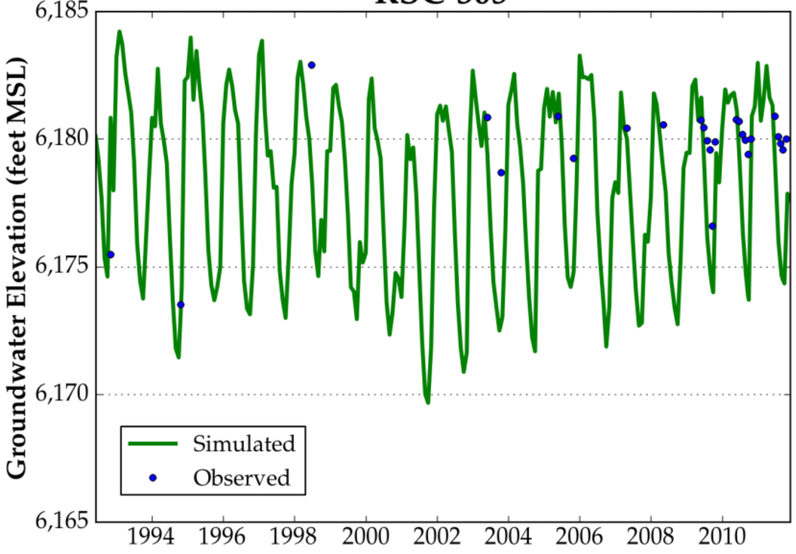

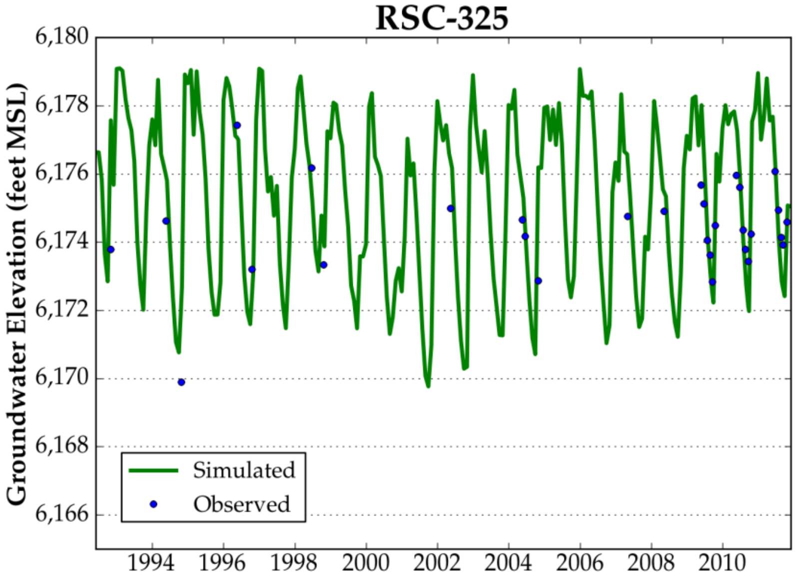
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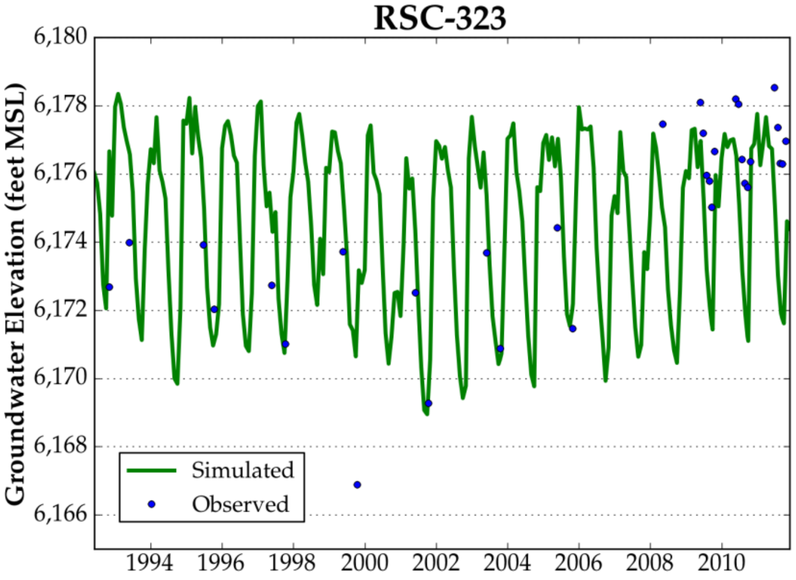
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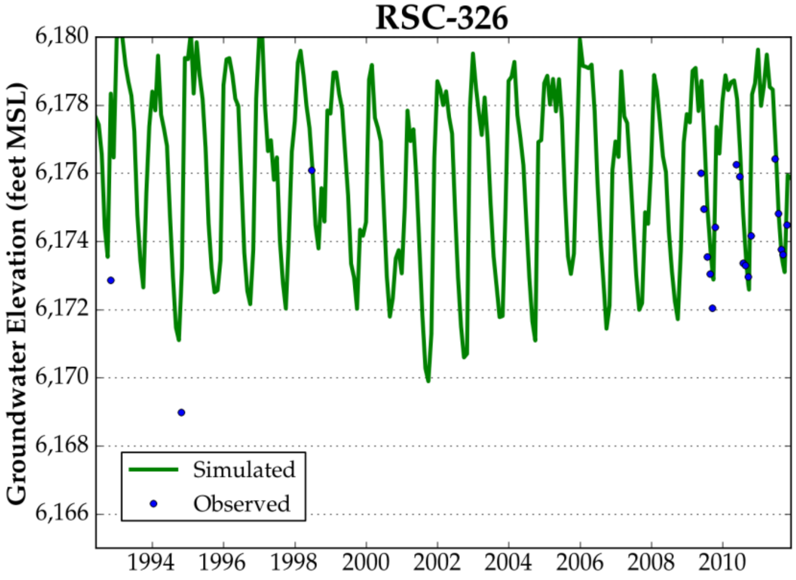
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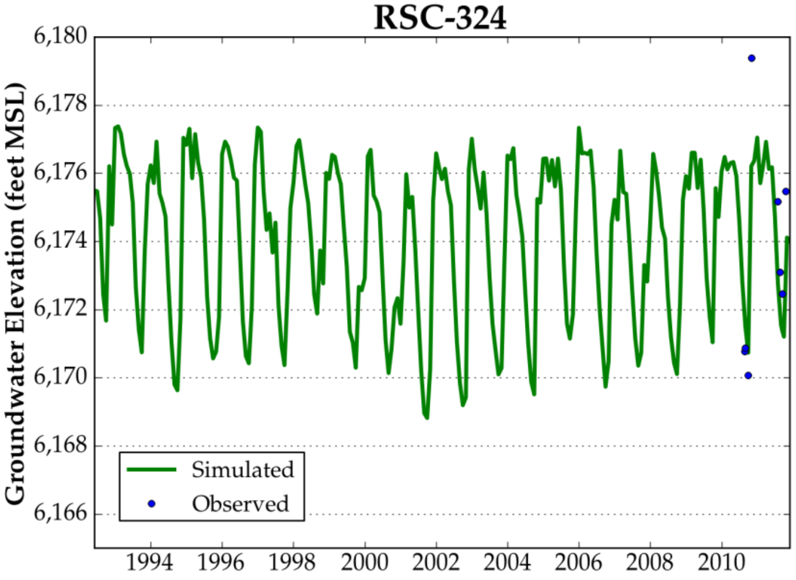
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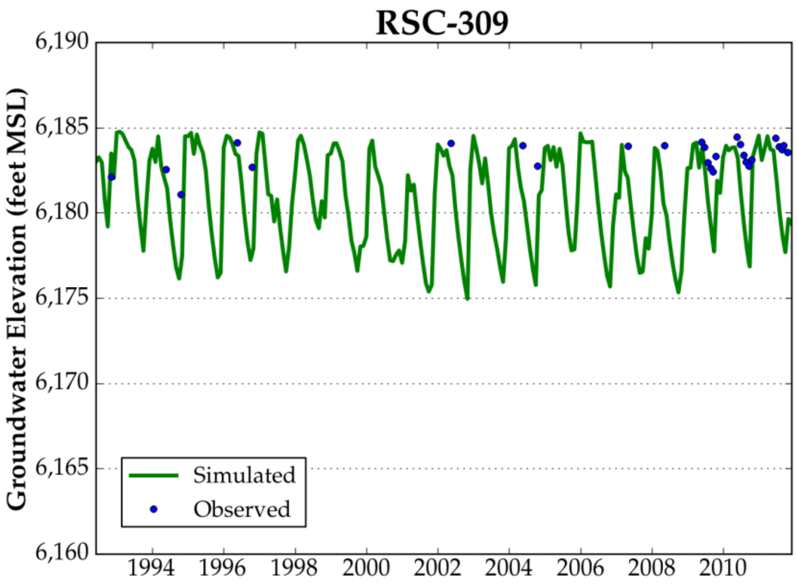

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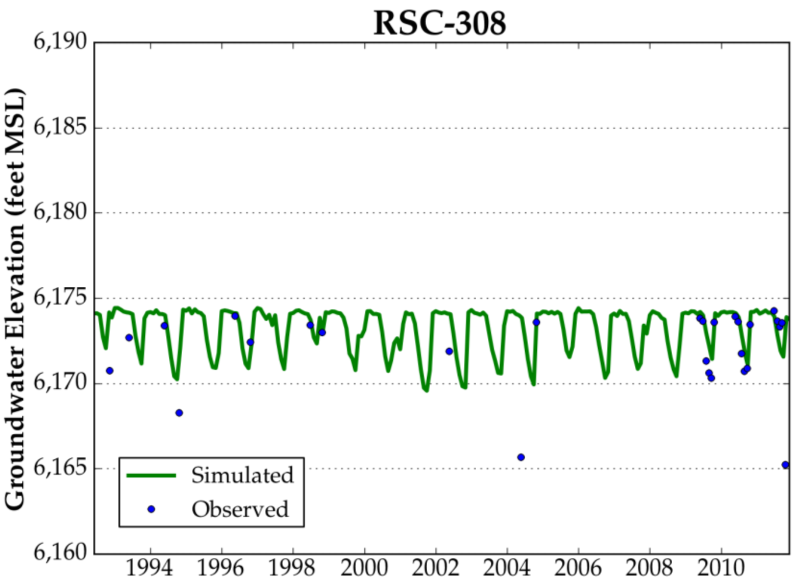

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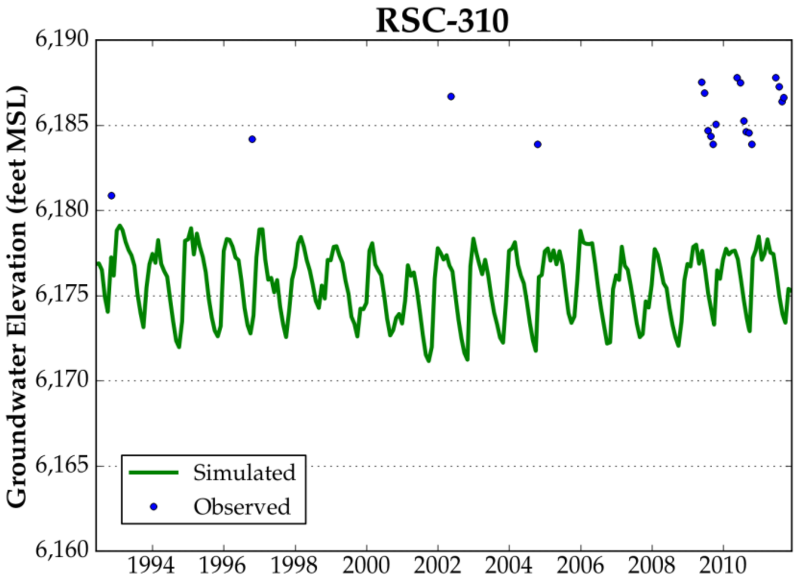

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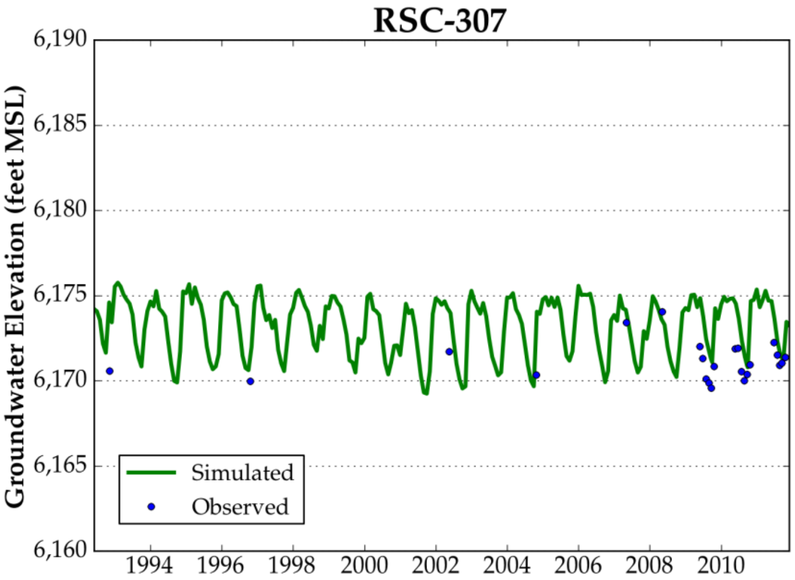

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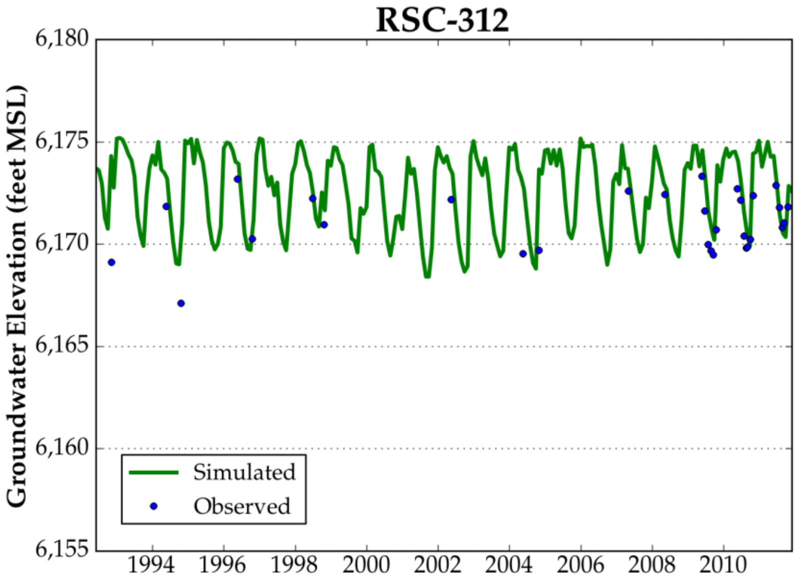
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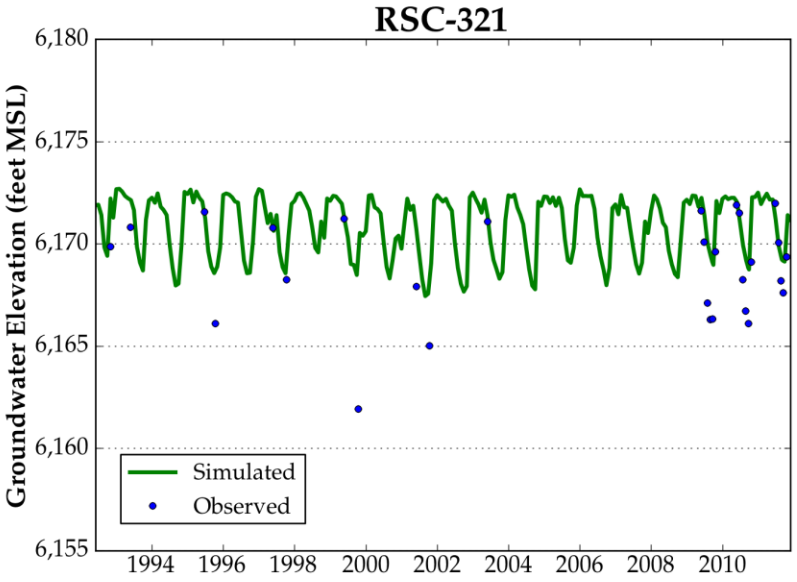
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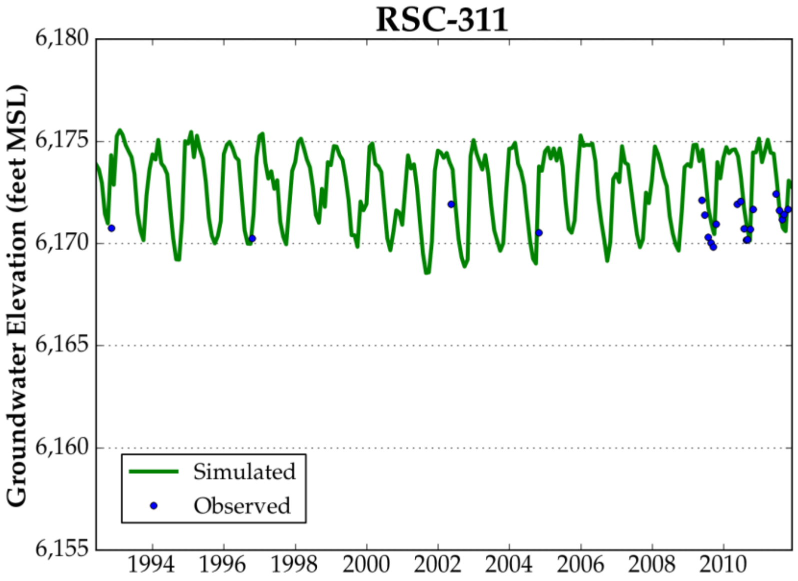
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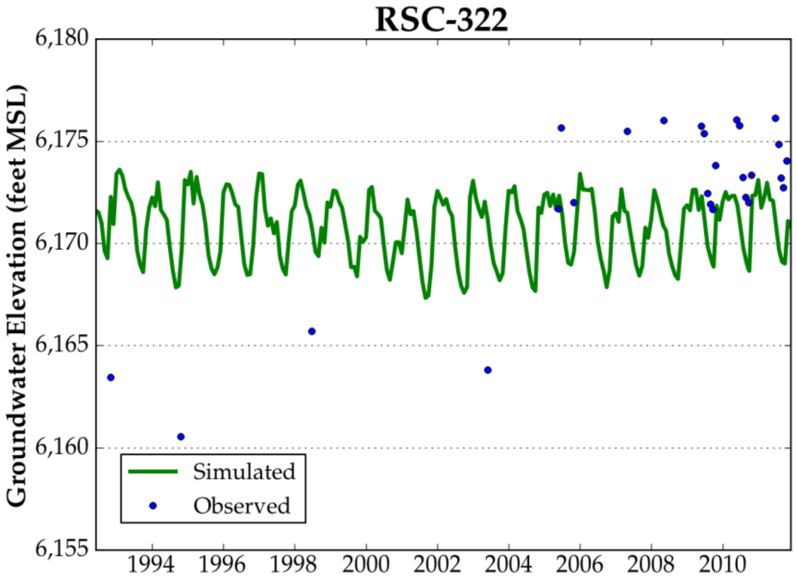
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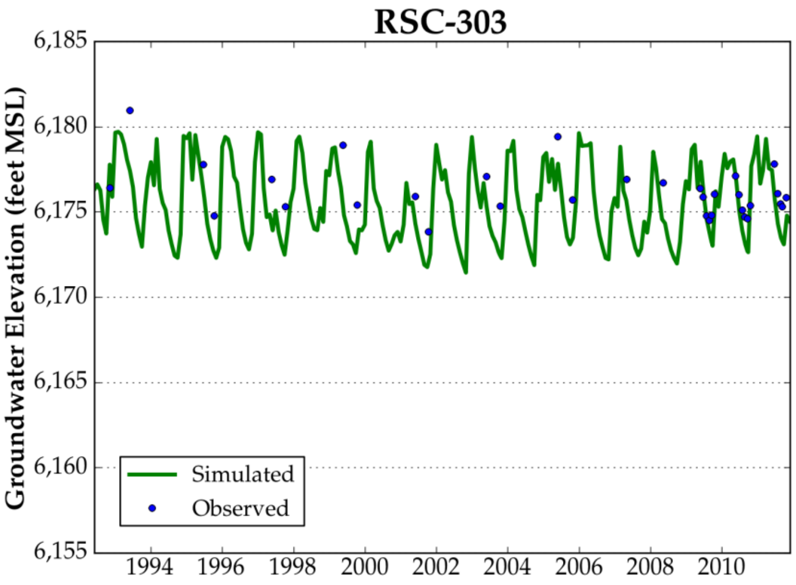
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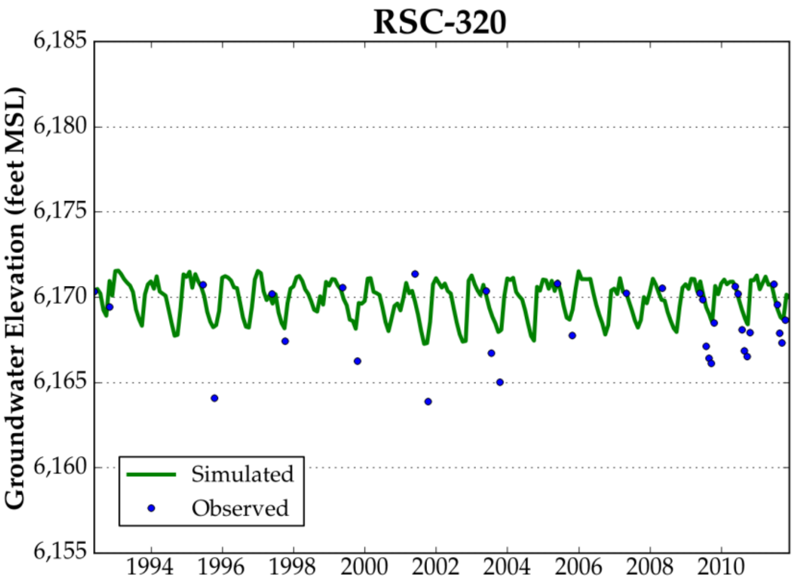
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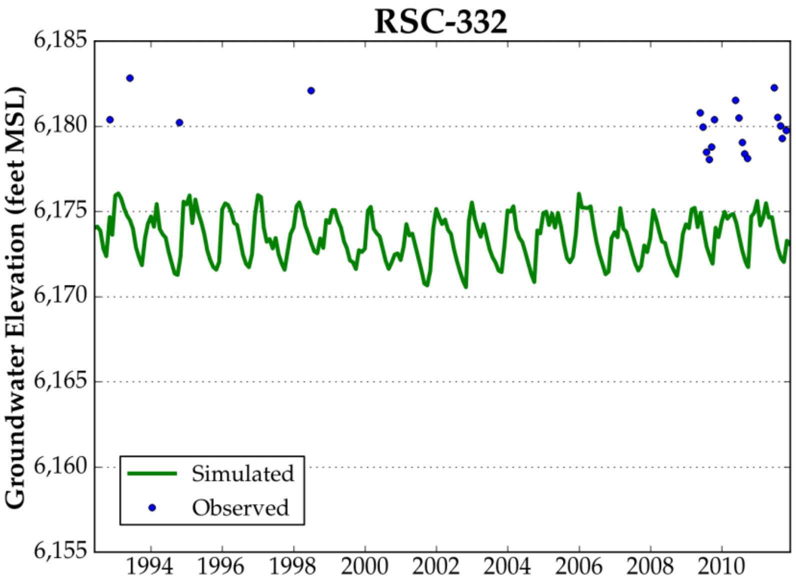
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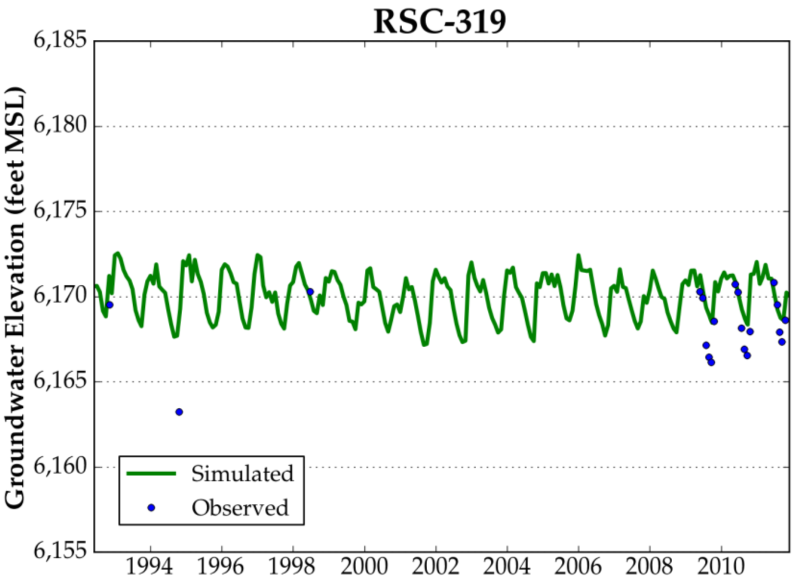
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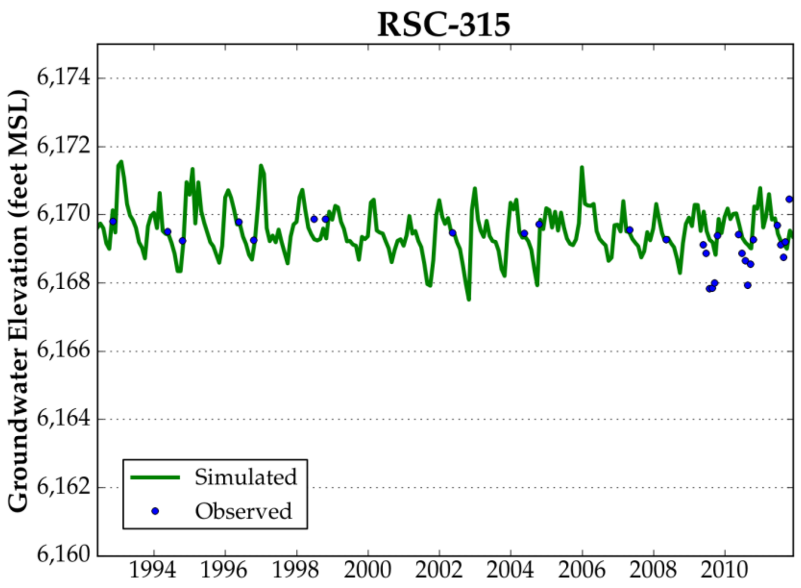
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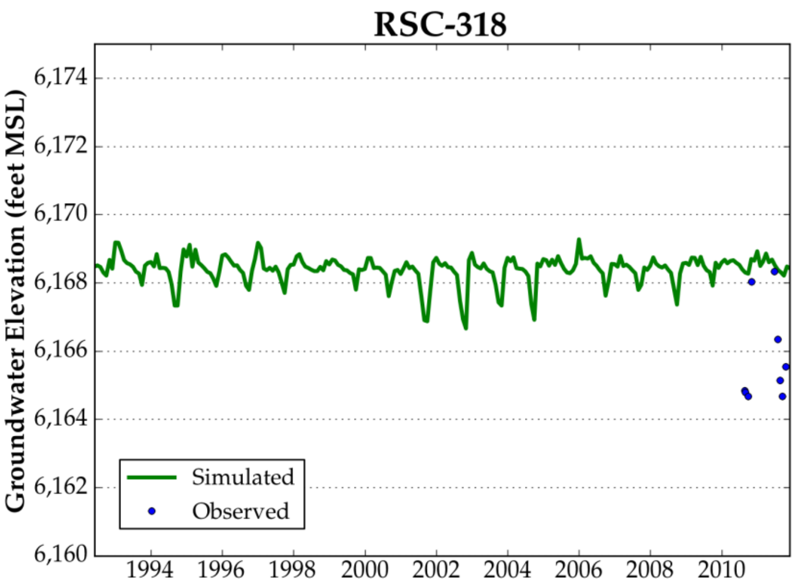
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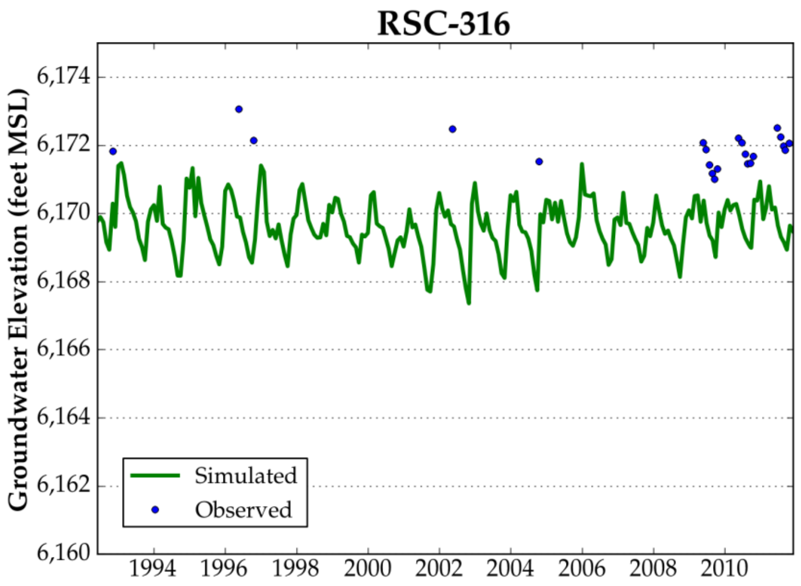
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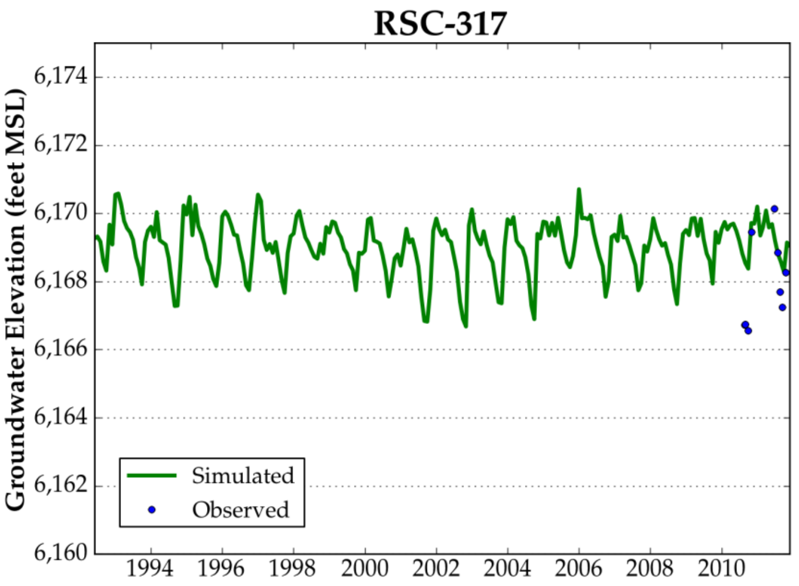
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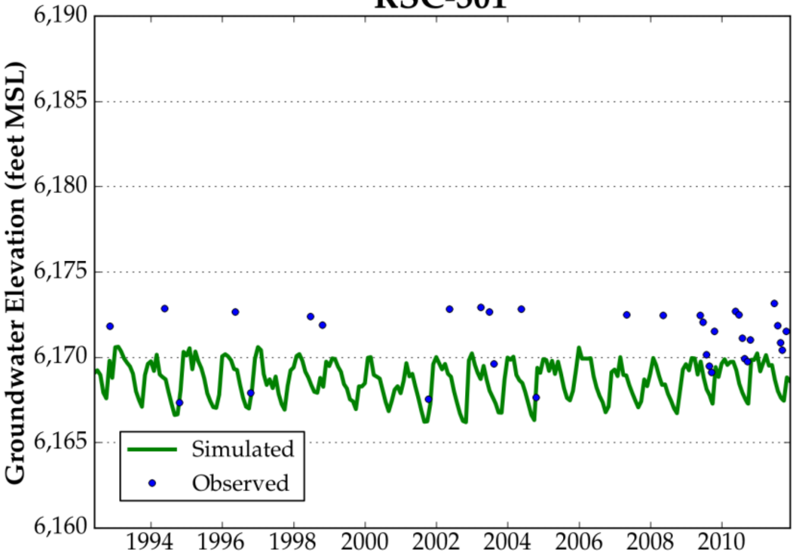
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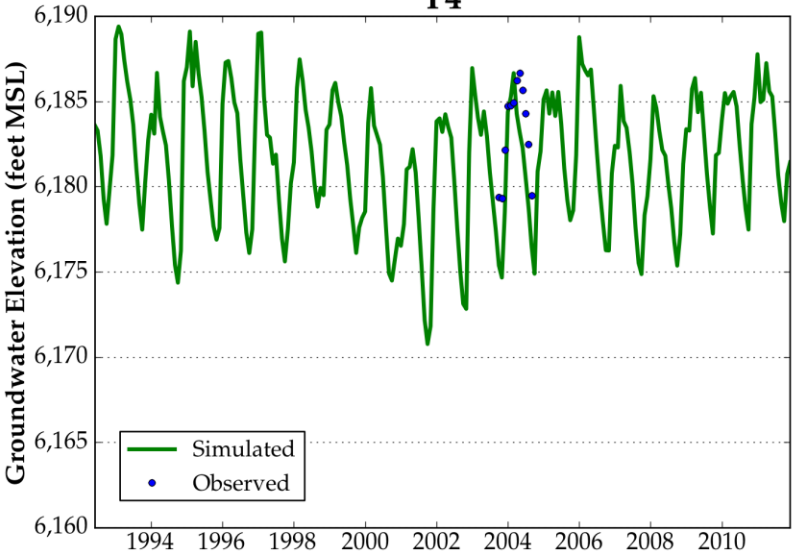
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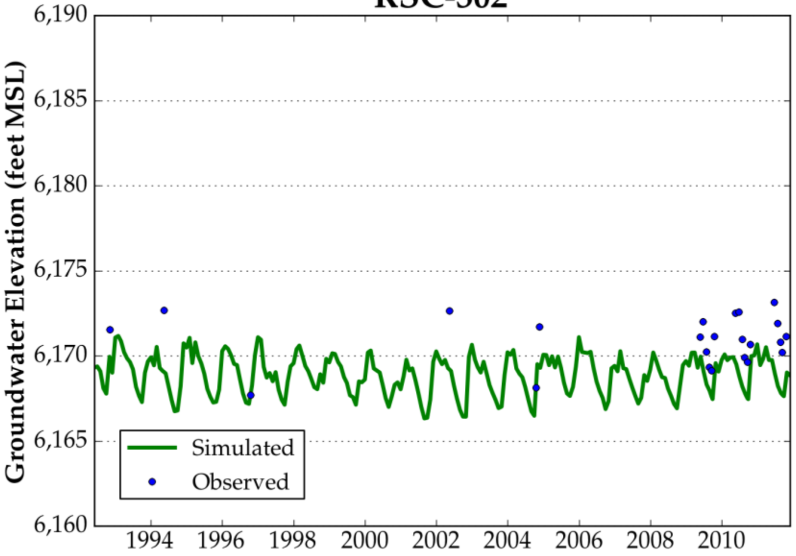
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Examination of Groundwater Inflow to Squaw Creek using Radon and Other Tracers

Prepared for:
Squaw Valley Public Service District

October 2013

Prepared by:
Dr. Jean Moran, PhD

Executive Summary:

In 2008 and 2009 investigators from Lawrence Livermore National Laboratory (LLNL), the University of Nevada at Reno (UNR) and California State University East Bay (CSUEB) examined surface water-groundwater interaction in Squaw Creek using isotopic and geochemical tracers. The research was part of a larger study aimed at investigating the vulnerability of groundwater and stream baseflow to predicted future climate change (Singleton and Moran, 2010). The goals of the study were to identify locations or reaches along Squaw Creek where groundwater enters the stream and to quantify groundwater influx to the stream. The main geochemical tool applied to achieve the study goals was radon, a naturally-occurring dissolved gas isotope found in surface water only in proximity to groundwater inputs. Ancillary data used to examine stream-groundwater interaction included stable isotopes of hydrogen and oxygen, and heat, as recorded using Distributed Temperature Sensing.

Radon activity was measured along a 3 km reach of Squaw Creek at 20 m intervals in two sampling surveys. A simple mass balance model of stream radon activity was developed that considered only groundwater discharge as a radon source, and gas emanation as a radon sink. A best fit model to observed radon stream activities was obtained by varying groundwater discharge along the length of the stream. Using this simple model, groundwater discharge along the study reach was estimated to be about 5% of total stream discharge in early June, 2009 (near the peak of the hydrograph during spring snowmelt) and about 18% of total discharge in early July, 2009. Stream gauge data indicate an even higher fractional contribution of groundwater influx during the initial stage of snowmelt runoff. By late July and August, groundwater inflow makes up nearly all of the observed flow in Squaw Creek.

Geochemical tracers like radon offer only a snapshot of the influx conditions over the study period of a few days, but unlike stream gauge data, provide information about the spatial variability of groundwater input to the stream. In both the June and July sampling events, major groundwater influx hotspots were not observed, indicating that groundwater influx is uniformly distributed over the study reach. This conclusion is in agreement with Distributed Temperature Sensing results, which indicate continuous, gradual input of groundwater that is slightly warmer than surface water in early July.

Background:

Baseflow in sub-alpine streams like Squaw Creek is crucial for maintaining riparian and stream ecosystem health. Baseflow, supplied by groundwater inflow long after snowmelt runoff ends, regulates water temperature and maintains pools that act as refugia for fish and other macro-organisms. At baseflow, the total influx of water to the stream from groundwater and total flow generated may be very small (0.02 cfs or less), but the consequences of cessation of baseflow are dire for the stream ecosystem. Sources of water that contribute to baseflow can be difficult to identify since groundwater may enter the stream over discrete reaches and groundwater travel times to the stream may vary from seasonal to decadal. Groundwater age dating in Olympic Valley wells indicates that the mean travel time for groundwater contributing to baseflow in the upstream portion of Squaw Creek (near the main production wells) is short, only one to two years, highlighting the importance of seasonal recharge of snowmelt (SINGLETON AND MORAN, 2010) for maintaining baseflow.

Stream gauge (discharge) data can be used to assess groundwater inflow by monitoring increases in streamflow not accounted for by tributaries or overland flow. On Squaw Creek, three stream gauges provide good temporal resolution of stream discharge (figure 1). However, at least three ungauged tributaries enter the main stem between the gauging stations, so the measured increase or decrease in flow cannot be attributed exclusively to gain from or loss to the groundwater system. Moreover, large, short term variations in flow during the snowmelt runoff period do not allow the direction of flow (gaining or losing) to be determined during high flow periods. Nonetheless, it is clear from stream discharge data for 2008 and 2009 that over much of the year, Squaw Creek is likely gains water downstream of the confluence of the two main tributaries, and that late season flow is supplied by groundwater influx. During small runoff events, and over a portion of the time period of peak runoff, groundwater inflow supplies a major portion of the stream discharge (figure 2 and figure 3). Assuming that the difference between downstream discharge and the sum of upstream discharge (with a one hour time lag) equates to groundwater inflow, the fraction of groundwater inflow varies as shown in figure 4, and the *total* annual groundwater inflow for 2008-2009 comprises 22% of discharge. Negative values on figure 4 are interpreted as times when the creek is losing water to the groundwater system. As expected, the percentage of discharge that is inflow is highest in late July and August when total discharge is very small. Interestingly, although average discharge and total discharge are greater for North fork than South fork, snowmelt flow duration is longer for South fork, which may be important for late season baseflow.

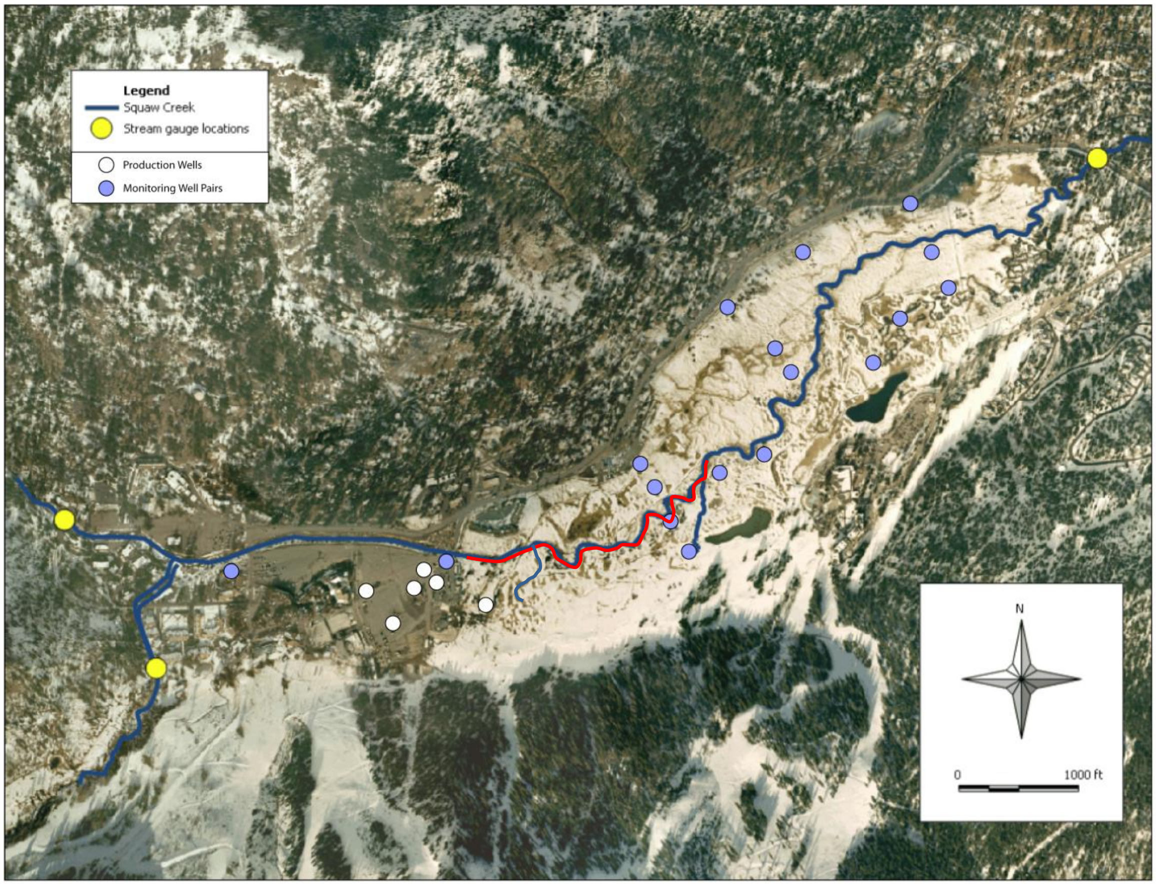


Figure 1. Stream gauge locations on the North Fork, South Fork, and Main stem of Squaw Creek shown as yellow symbols. Wells sampled for the groundwater residence time study shown as blue and white circles (Singleton and Moran, 2010). Squaw Creek reach examined by Distributed Temperature Sensing shown as red line. Two of the three or more ungauged tributaries are shown as blue lines entering Squaw Creek over the DTS study reach.

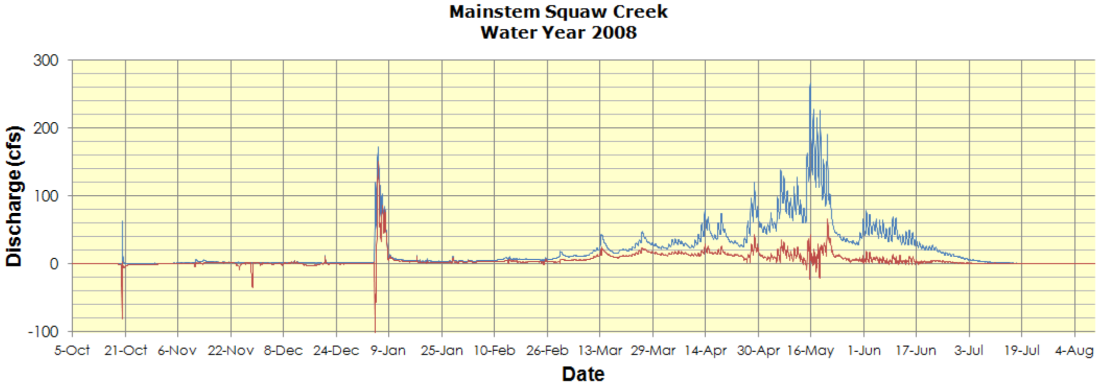


Figure 2. Stream discharge on the main stem of Squaw Creek (blue line), and 'inflow' (red line) as calculated from Q (main stem)-[Q (north fork) +Q (south fork)] with a one hour time lag for water year 2008 (fall, 2007- fall, 2008).

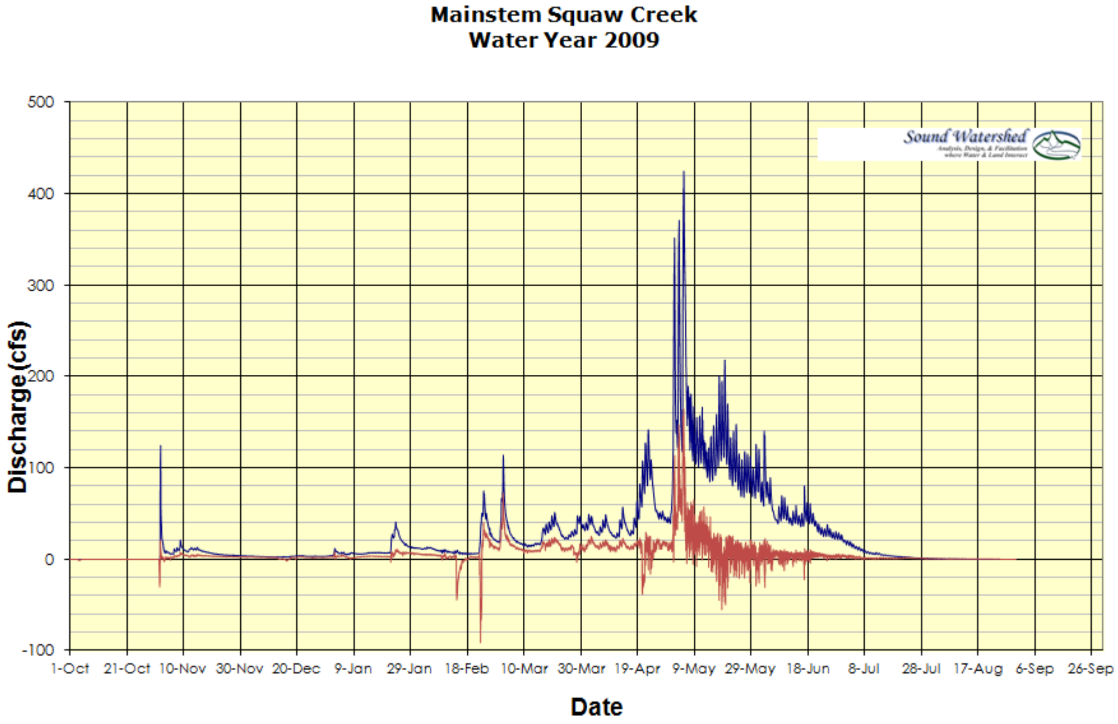


Figure 3. Stream discharge on the main stem of Squaw Creek (blue line), and 'inflow' (red line) as calculated from Q (main stem)-[Q (north fork) +Q (south fork)] with a one hour time lag for water year 2009 (fall, 2008-fall 2009).

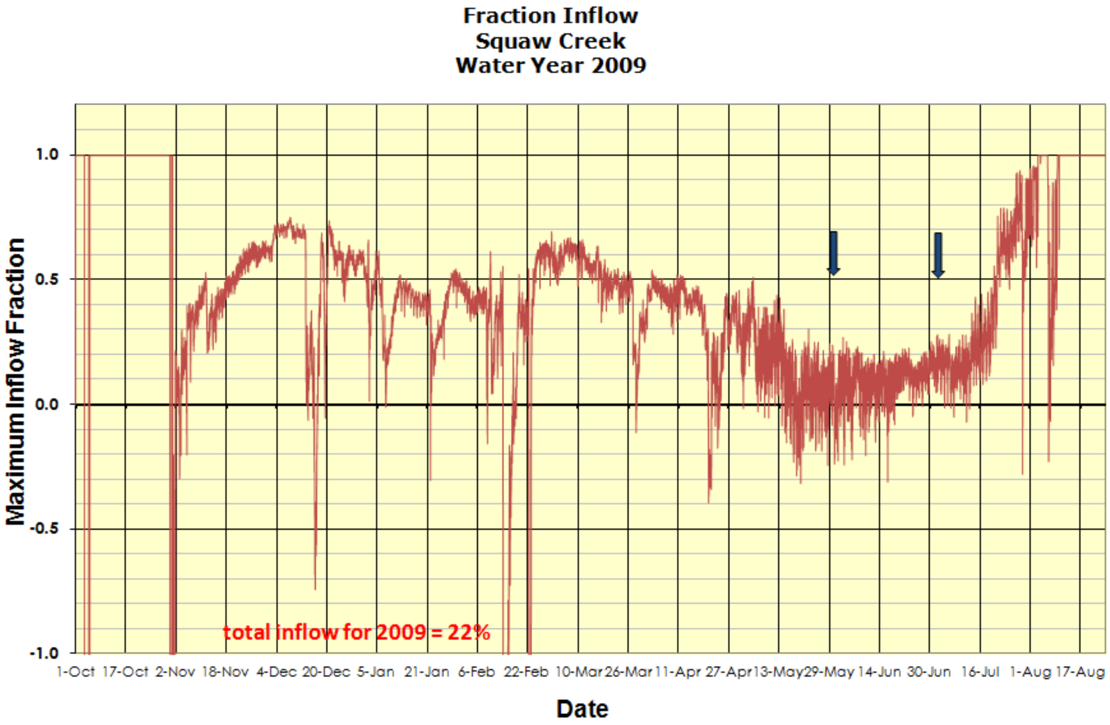


Figure 4. The fraction of the total flow that is groundwater inflow is calculated using the discharge data shown on Figure 3. The dates of the two radon surveys are indicated by blue arrows.

While hydrologic parameters (stream gauge data and hydraulic head measurements in wells adjacent to the stream) provide good temporal resolution for examining stream-groundwater interaction, spatial information is sparse. For Squaw Creek, the three gauges are useful for determining the timing of peak runoff, and for making a semi-quantitative determination of inflow over the reach between the gauges. Uncertainty is introduced because tributaries are not gauged. In contrast, geochemical parameters provide good spatial resolution for examining stream-groundwater interaction, but are synoptic, lacking in temporal resolution. Uncertainty in the analysis is introduced because the geochemical characteristics of the groundwater contribution likely vary in time. In addition, geochemical tools work best when groundwater influx is a significant portion of the total discharge. So, while the period of time over which discharge is dominated by snowmelt runoff is important because it makes up the vast majority of the streamflow, interpretation of geochemical patterns is more uncertain over that time period since influx is a small and variable portion of the total discharge.

Methods:

Distributed Temperature Sensing (DTS)

Distributed temperature sensing (DTS) has been used to study groundwater-surface dynamics in detail over stream lengths of up to 2 km (e.g., LOWRY ET AL., 2007; ROSE ET AL., 2013). Heat tracing can yield spatially refined estimates of relatively modest groundwater inflow even in large rivers. DTS heat tracing, in particular, provides fine-scale spatial characterization of groundwater inflow, and is universally applicable compared to geochemical methods, which require a distinct groundwater end-member. DTS uses the properties of a fiber optic cable to measure temperature. The fiber optic cable serves as the thermometer, with a laser serving as the illumination source. Measurements of temperature every 1 m are resolved every 1-2 minutes, with an uncertainty of about 0.2°C.

The University of Nevada at Reno deployed a one kilometer long distributed temperature sensing apparatus in Squaw Creek on July 1 and July 2, 2009 over a one kilometer reach beginning at the bridge downstream of the trapezoidal channel (red line on figure 1). The cable was placed in the central portion of the streambed, following meanders and coiled at the bottom of pools (figure 5). Short lengths of cable were placed a few meters upstream in two tributaries. The DTS is calibrated using ice baths and constant temperature baths at the beginning and end of the cable. During the deployment, the downstream calibration bath experienced temperature fluctuations and readings were not within the tolerance for calibration to the desired level of accuracy. Therefore, quantitative DTS results cannot be reported with confidence, and interpretation of the results is focused on qualitative aspects.

Stable Isotopes of the Water Molecule

Stable isotopes of hydrogen and oxygen were used to examine sources of water to Squaw Creek, building on well-established patterns observed for these isotopes in precipitation and runoff (KENDALL AND CALDWELL, 1998). The minor stable isotopes of water molecules ^{2}H (deuterium, denoted as D) and ^{18}O vary in precipitation as a function of temperature, elevation and latitude (CRAIG, 1961). Oxygen isotope ratios are reported in the standard delta (δ) notation as parts per thousand (per mil or ‰) variations relative to a reference material of known composition and defined by the following equation:

$$\delta_x = 1000\frac{R_x - R_{std}}{R_{std}}$$

Where, for oxygen, R_x is the $^{18}O/^{16}O$ ratio of the sample and R_{std} is the $^{18}O/^{16}O$ ratio of the standard. The conventional standard reference material for oxygen isotopes is Standard Mean Ocean Water (SMOW; CRAIG, 1961). Using the delta notation, $\delta^{18}O$ in precipitation varies from approximately -4‰ along the Pacific coast to -15‰ in the Sierra Nevada mountains and δD and $\delta^{18}O$ are related linearly in meteoric water.

In general, the lighter isotopes of H and O are concentrated in precipitation formed in colder air masses (higher elevation) compared to precipitation formed in warmer air masses (lower elevation). In Olympic Valley, snowmelt runoff from the top of the watershed is therefore expected to have a significantly lighter (more negative relative to SMOW) isotopic signature than runoff from lower elevation snow. After deposition of precipitation, evaporation of water prior to recharge causes a shift in the isotopic ratio to heavier (less negative) values.

Isotope ratios of groundwater, surface water (creeks), and precipitation (snow) from Olympic Valley were analyzed at LLNL and at CSUEB using standard techniques and are reported relative to Standard Mean Ocean Water (SMOW) as per mil deviations from the international standard, using delta notation (KENDALL AND CALDWELL, 1998). Analytical uncertainties are +/- 0.15 per mil for $\delta^{18}O$ are and +/- 1.0 per mil for δD.

Radon

Radon (^{222}Radon) is a powerful geochemical tracer for quantifying groundwater discharge to streams (COOK ET AL., 1999, COOK ET AL., 2006). Radon is a naturally-occurring, gaseous daughter product in the 238-Uranium decay chain with a half-life of 3.8 days. Groundwater contains dissolved radon because aquifer materials contain uranium, and recoil during natural fission allows daughter products to enter circulating groundwater. When groundwater containing dissolved radon discharges to surface water, radon is released in the gas phase to the atmosphere. High radon activities are present in surface waters in the immediate vicinity of points of groundwater inflow, and for relatively short distances downstream of those locations. Quantification of groundwater discharge to streams using radon relies on knowledge of the gas exchange coefficient, the groundwater radon concentration, and possible contributions of radon from hyporheic zone sediments, as described below.

Radon in Squaw Creek

Water samples were collected by injecting 10mL of water into a scintillation vial beneath a mineral oil cocktail. This technique allowed for minimal degassing of radon from the sample and rapid counting. In addition to numerous stream samples, groundwater and hyporheic zone water samples were analyzed for comparison. Over the two days of sampling conducted in June, a significant amount of rain occurred in the afternoons and evenings, which is observed in the stream gauge data. Radon activities were measured within two days of sampling, using a Quantalus 1220 liquid scintillation counter at Lawrence Livermore National Laboratory.

Hyporheic Zone

Beneath and along streambeds, surface water and shallow groundwater exchange in the hyporheic zone: a key region for biogeochemical reactions and oxygen exchange. Water may reside in the hyporheic zone for minutes to days, and radon may accumulate in porewater there. Two drivepoint piezometers, with 20 cm screens, were deployed during the July field session in order to sample hyporheic zone water and sediments. Water samples for radon analysis were collected from the drivepoint using a hand-operated vacuum pump the day after installation. Streambed sediments were also sampled from the drivepoint locations for radon emanation experiments.

Results and Discussion:

Heat tracing with DTS

Temperature data from the DTS are displayed in figures 6 and 7. On figure 6, distance along the DTS cable is plotted on the x-axis. Time is plotted on the y-axis, with time increasing upward. The colors on figure 6 represent measured water temperatures. Therefore, color changes in the vertical direction (y-axis) represent creek temperature changes over time at one location. Color changes in the horizontal direction (x-axis) represent temperature changes along the length of the study reach at any one time.

Figure 7 graphs creek temperature changes at two specific points in time: 1:00 am on July 1, 2009, and 11 AM on July 1, 2009. These times were chosen to be representative of water temperature changes in Squaw Creek at night and during the day, respectively. The data graphed on figure 7 are equivalent to the temperature changes shown by the colors on figure 6. The two time periods graphed on figure 7 are shown on figure 6 for reference.

A large temperature range was observed in stream DTS data (7.5°C to 13°C), in the vertical (time) direction on figure 6. The large temperature range in the stream is the result of diurnal heating and cooling of the creek water. Even larger diurnal swings are observed at locations where the cable came out of the stream and was exposed to air (noted on figure 7). While daytime data are affected by temporary cloud cover and other shadows, and by afternoon pulses of snowmelt runoff, night time data are much less noisy. Night time data are therefore given more weight in the interpretation of DTS results. Groundwater discharge temperatures (measured during well sampling using a YSI 556 multi-meter), ranged from 6.5°C to 12°C. Monitor wells in the golf course/meadow area exhibited a smaller range of 9°C to 10.5°C, which is close to temperatures measured in pore water in the drivepoint samplers (8.8°C to 9.6°C). Nine to ten degrees C is therefore the likely range for the temperature of groundwater influx along the DTS study reach.

Figure 5. Distributed temperature sensing (DTS) cable in Squaw Creek on July 1, 2009.

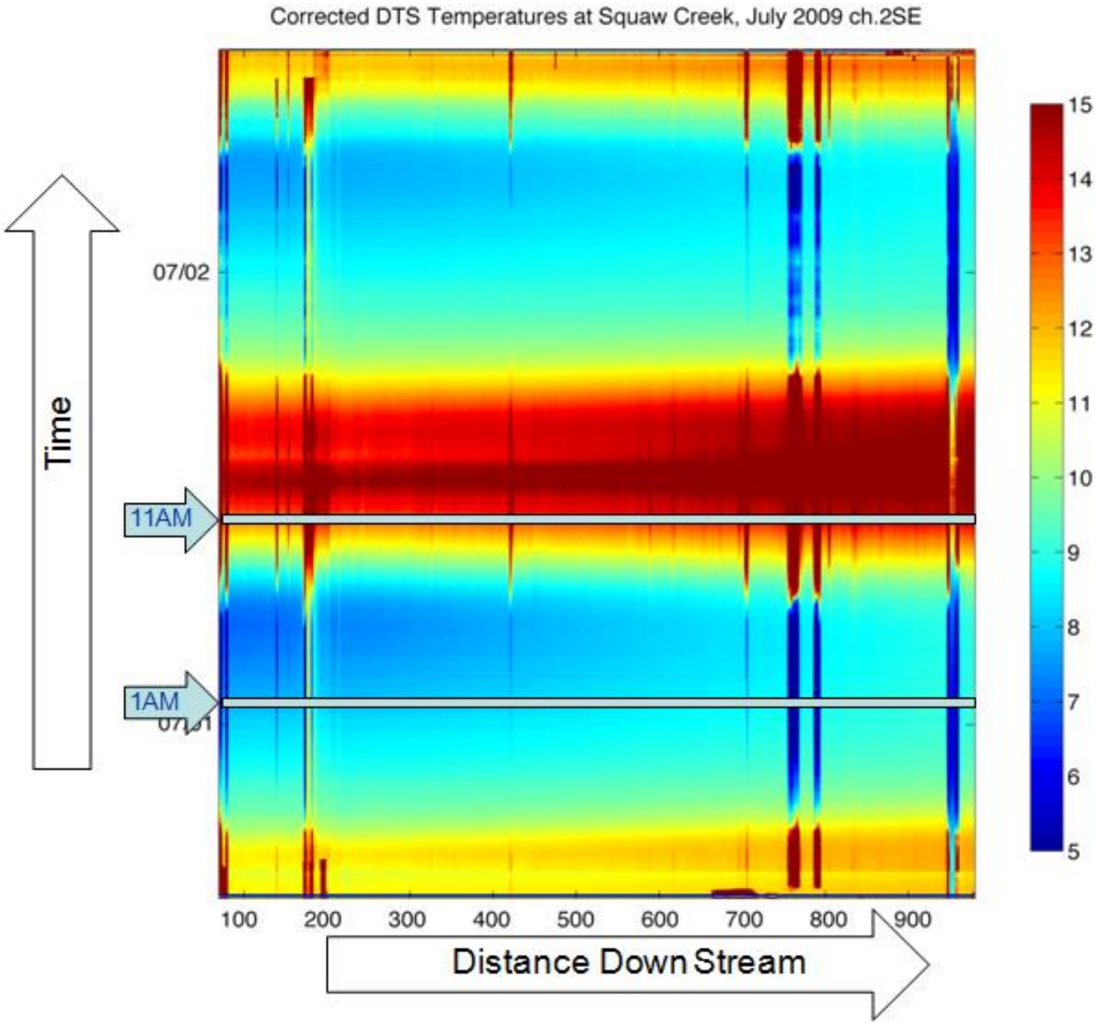


Figure 6. Distance-time plot with temperature data from DTS survey. A slight, gradual warming trend is observed with distance downstream. Large anomalies are due to diurnal air temperature oscillations at locations where the cable was out of the water.

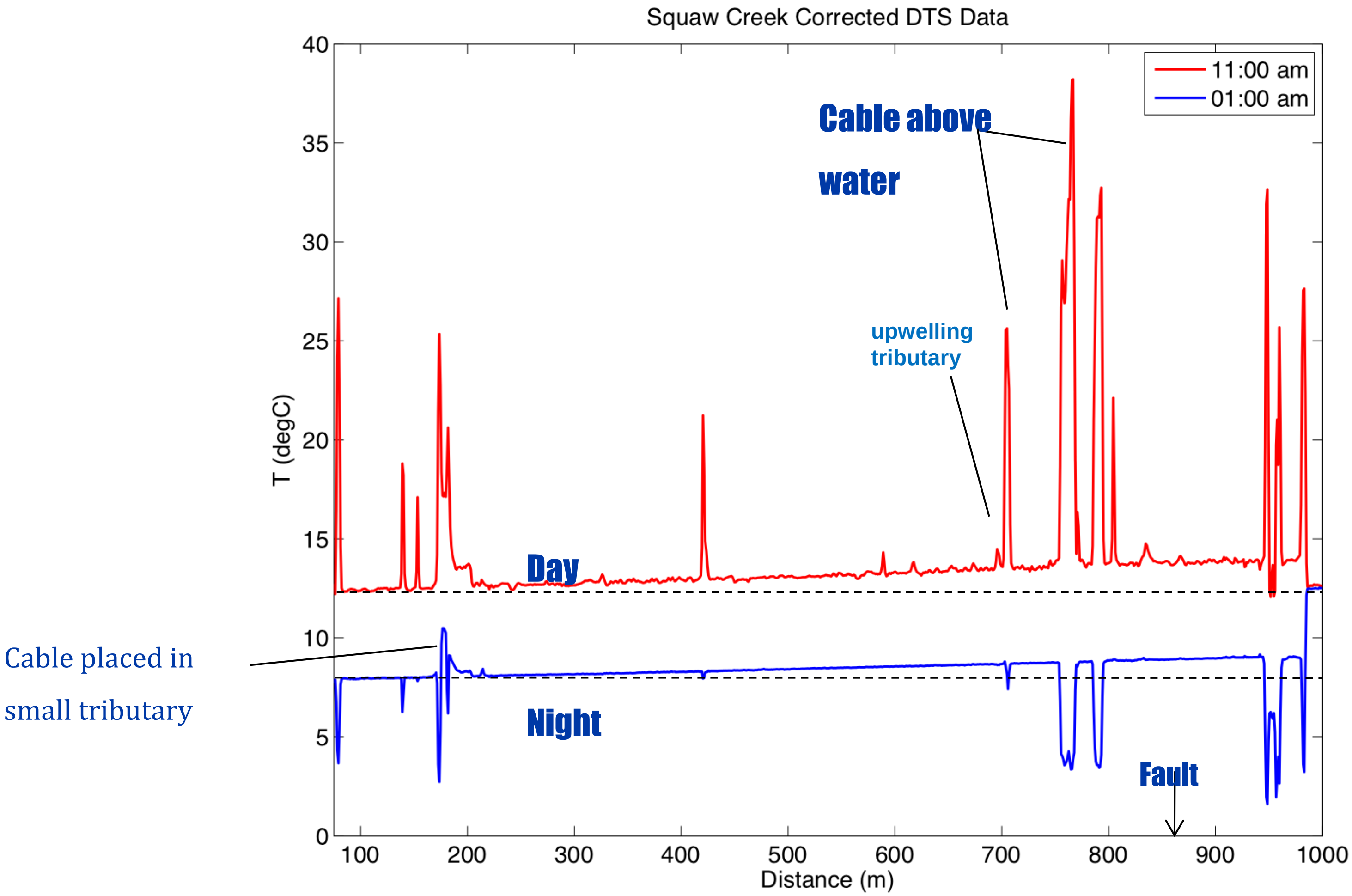


Figure 7. Two single time DTS traces from 1 am and 11 am on July 1, 2009. An upstream tributary, at a higher temperature than the main stem, and a downstream tributary ('upwelling' outflow), at a lower temperature than the main stem, are identified, along with locations where the cable is exposed to the air, with warm deflections during the day and cold deflections at night.

Overall, for night time data, there is a slight, gradual increase in the stream temperature with distance downstream (figure 7), indicating that groundwater influx (at slightly higher temperature than stream water) results in a slight warming of stream water. Two tributaries, one near the beginning of the study reach and one near the end ('upwelling' discharge), result in warm and cool deflections from the overall gradually increasing trend, respectively. The lack of any other significant deviations from the overall gradual increase indicates that groundwater influx is not focused at discrete locations, but rather is distributed evenly along the study reach. Similarly, lack of evidence for localized influx at locations where faults cross the stream suggests that if faults are a conduit for groundwater flow, the flow is not a significant component of the discharge carried by the stream. (The location of one fault, with a surface expression in the stream bank, is noted on figure 7 at 880m.)

Stable Isotopes of the Water Molecule in Groundwater and Squaw Creek

Results of stable isotope analyses are plotted against time in figure 8. Overall, the range in oxygen and hydrogen isotope ratios (expressed as $\delta^{18}O$ and δD) observed in all Olympic Valley samples is consistent with water derived from precipitation. The three precipitation (snow) samples (green symbols on figure 9) were collected from the top of the ski runs (lightest ratio), High Camp, and in the meadow (heaviest ratio). Most surface water and groundwater values fall between the middle (High Camp) and low elevation (meadow) values, indicating that most water is derived from the lower slopes and valley area. (Most of the surface area for snow accumulation is also within this elevation range, with relatively little total area for accumulation above High Camp.)

Frequent sampling at several locations along the stream during the snowmelt runoff period in 2008 reveal a tight grouping for all locations and no significant differences in sources of water along the study reach. A gradual trend toward a 'heavier' (less negative) isotope signature is evident over the snowmelt period from April through July. The pattern of snowmelt becoming isotopically heavier as the melt season progresses, including the abrupt increase as the last snow melts, has been observed in other high elevation streams dominated by snowmelt runoff (LEE ET AL., 2010, TAYLOR ET AL., 2001). The observed pattern is the result of preferential release of the lighter isotopes during melting and enrichment (i.e., increase in $\delta^{18}O$ and δD) through time in the snowmelt that enters the stream (TAYLOR ET AL., 2001). Secondarily, superimposed on this pattern, is the effect of lower elevation snow (less negative, relatively enriched in the heavier isotopes) melting earlier than higher elevation snow.

Figure 9 shows $\delta^{18}O$ and δD for Olympic Valley samples, along with the Global Meteoric Water Line (GMWL) that defines the trend expected for all meteoric water (CRAIG, 1961). Most Squaw Creek and Olympic Valley groundwater samples fall in the same range, close to the GMWL and bracketed by the range observed for snow samples from Olympic Valley, confirming that meteoric water is the dominant source of all water in the valley. During August, 2008, when water in the Creek was dominated by baseflow, several samples were collected at the downstream gauge station. These samples have isotopic values that plot below the GMWL, which is evidence for evaporation (figure 9, yellow symbols). Two other samples, collected in cool pools upstream from the stream gauge location at the same time, had isotopic values that showed no evidence for evaporation. This pattern indicates that some late season pools (e.g., the pool near the gauge location) are standing water that is evaporating, while the upstream pools that were sampled are continually fed by groundwater influx.

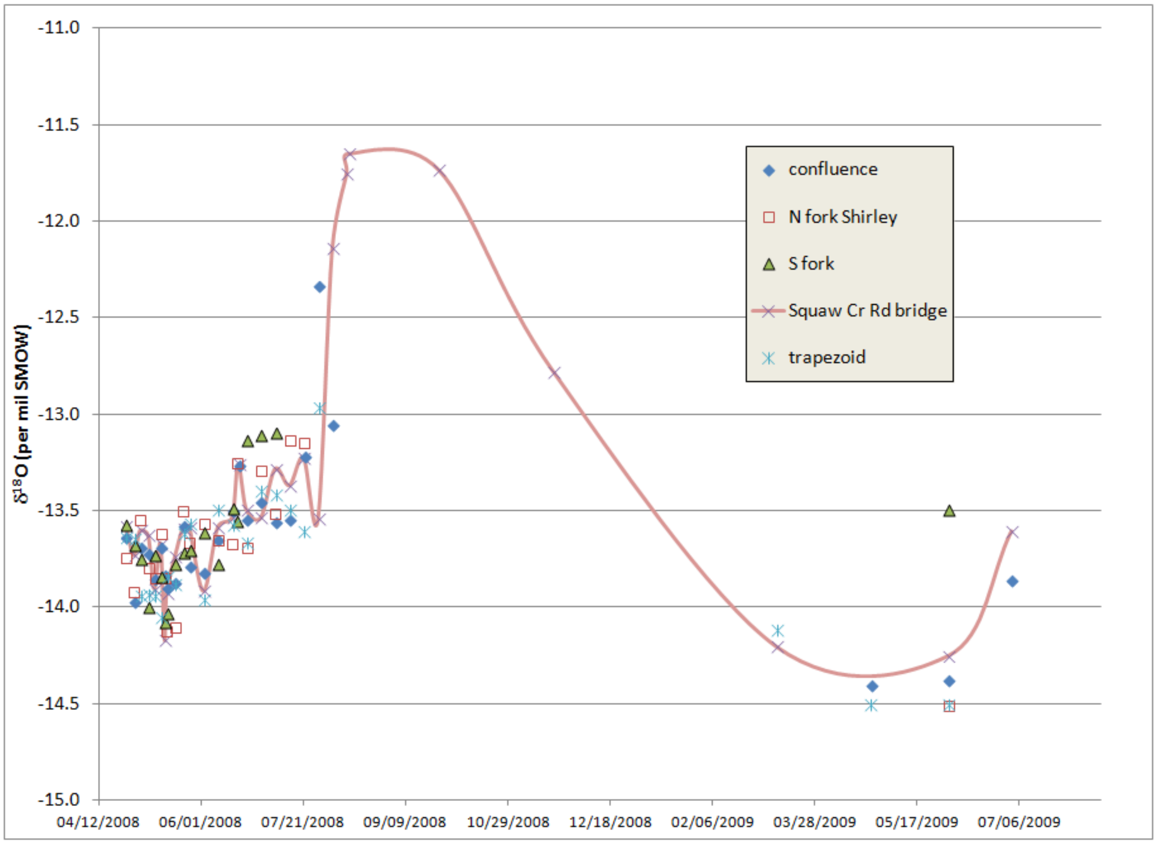


Figure 8. Oxygen isotope ratio in water samples from various locations along Squaw Creek, plotted against sampling date.

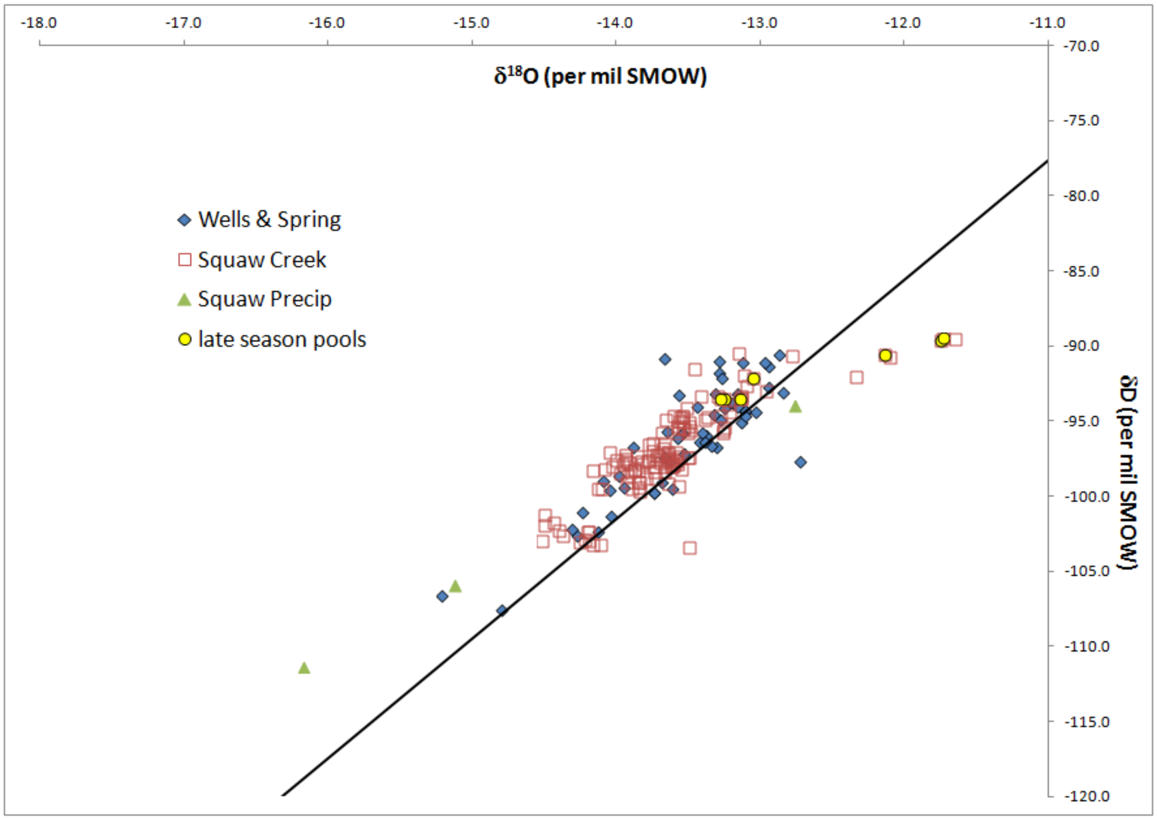


Figure 9. Stable isotope values for groundwater, surface water, and meteoric water from Olympic Valley, compared to the Global Meteoric Water Line (GMWL). Samples from isolated, late season pools in Squaw Creek are shown with yellow circles – samples falling below the line are from an evaporating pool at the downstream gauge, while the other yellow symbols show data from upstream pools fed by groundwater.

Radon in Groundwater

Groundwater radon activities range from 45 to 637 picoCuries per Liter (pCi/L) (figure 10). The lowest values were measured in shallow monitor wells in the meadow, and the highest activity was found in the well in the Plumpjack parking lot. Shallow monitor wells are completed in low permeability material, do not produce much water, and are difficult to purge, which may have resulted in compromised radon samples. Production well values fall in a smaller range, centered around 400 pCi/L, and this is the value used for groundwater inflow concentration in the model (described below).

There are three tributaries along the study reach. The first enters around the first golf bridge downstream from the parking area. The second and third enter somewhat near one another about 700m downstream of the first golf bridge. One of these tributaries emanates from what is known as the "upwelling" and has an old, non-functioning weir installed on it. The other is about a tenth of a kilometer upstream from the upwelling and was dry in July. Although the first tributary had a very low radon activity, the upwelling had relatively high radon activity of around 240 pCi/L in both June and July, in the range observed for groundwater samples. This concentration mixes out quickly in the stream (discharge reaching the stream was quite low in June and near zero in July) and nearby sample measurements in the stream do not reflect this high value. DTS results show that the upwelling is colder than both the first tributary and the main stem of the Creek. The colder temperature, along with the high radon values is likely reflective of deeply sourced groundwater. There is also a fault trace visible in the stream bank near the location where the upwelling flow enters the stream. The upwelling may be related to this feature; however, the stream does not exhibit any large changes in radon as it crosses the fault, as noted above.

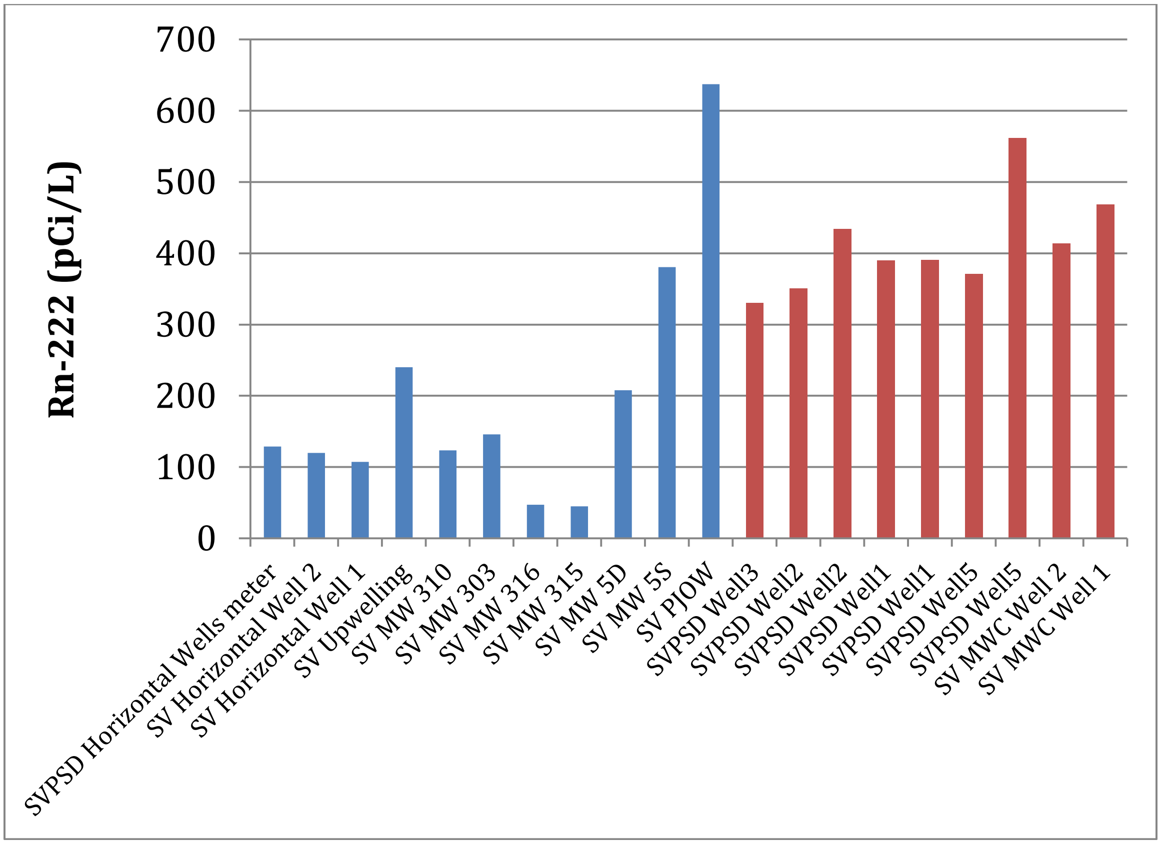


Figure 10. Radon activities measured in groundwater samples from Olympic Valley. Blue symbols represent low yield wells and red symbols represent production wells.

Radon in Stream Samples

As expected, because of its volatility, radon activities in stream samples are significantly lower than activities in groundwater samples. Results of the two synoptic stream surveys are shown in figure 11. Stream radon activities are higher in the July survey than in the June survey, reflective of a stream that contains a higher proportion of groundwater in July. This is consistent with what is expected for early summer as snowmelt runoff contribution decreases. Both June and July data exhibit small scale variability, which may largely be a function of analytical error, as displayed on figure 11. Overall, the lack of correlation between the curves and lack of large deviations from the mean value indicate that groundwater influx is not focused at discrete locations but rather is distributed roughly evenly over the study reach, corroborating the conclusion based on DTS results, and extending the stream length over which the observation applies. Relatively small downward deviations in the July data may indicate spatial variability in influx related to streambed sediment type variations or a change in aquifer lithology downstream of a major fault (figure 11). Both June and July results are above the method detection limit of approximately 20 pCi/L, indicating that Squaw Creek is gaining over the study reach, even during the period of high runoff.

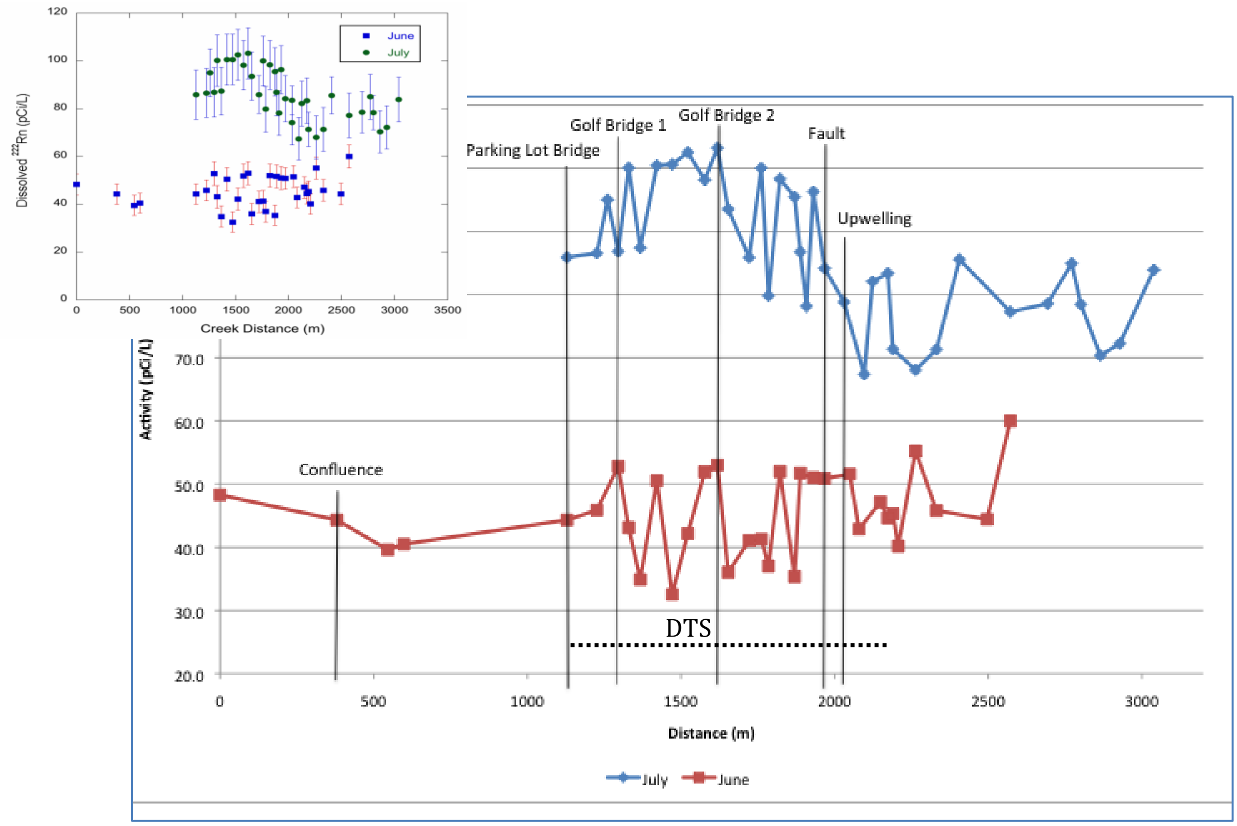


Figure 11. Measured radon activities in Squaw Creek, Olympic Village, CA. Radon activity (pCi/L) is potted against distance (m) downstream from the North Fork Weir. Data for July and June 2009 are shown. Also shown is the reach over which the DTS was deployed. Error bars on inset figure show analytical uncertainty in radon activity measurements.

Quantitative Interpretation of Stream Radon Results:

Theory

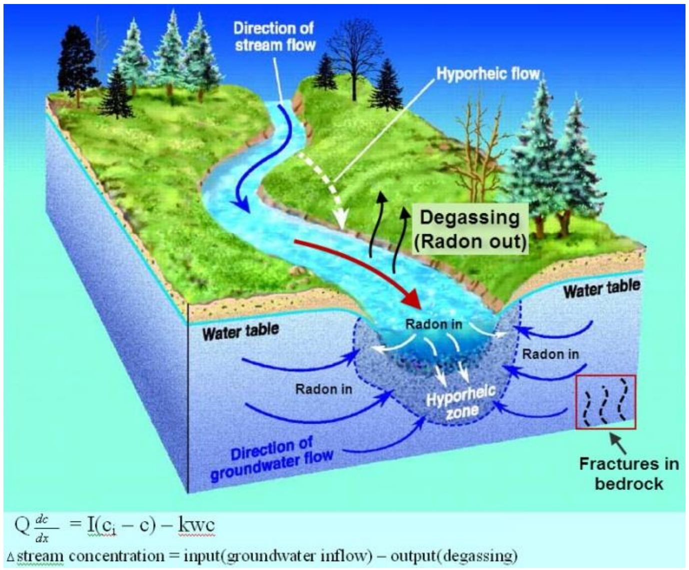
The stream radon results can be used to quantitatively estimate the flux of groundwater along the study reach. COOK et al. (2006) developed a steady state model for predicting radon concentrations in streams, with radon concentrations varying with distance but not time. The full model accounts for groundwater inflow, evaporation, radon degassing, radon decay, and hyporheic zone interaction (figure 12). Over the Squaw Creek study reach, evaporation and radon decay are negligible. Contribution of radon from hyporheic zone interaction was examined through analysis of radon emanation rates from streambed sediments. Finer grained sediments had higher emanation rates than coarse sands and gravels, but overall, emanation rates were low for the sediments examined, and are not included in the calculations of groundwater influx.

Thus, a simpler model can be applied that involves only groundwater inflow (with groundwater radon activity assumed constant), and radon degassing. The formula used to calculate groundwater inflow from radon concentrations along the length of Squaw Creek is:

$$Q\frac{dc}{dx} = I(c_i - c) - kwc$$

where

Q = stream discharge (m^3/day),
c = stream Radon activity (pCi/L),
c_i = groundwater Radon activity (pCi/L),
I = groundwater discharge (m^3/m/day),
w = stream width (m), and
k = gas transfer velocity (m/day).



$$Q\frac{dc}{dx} = I(c_i - c) - kwc$$

Δ stream concentration = input(groundwater inflow) − output(degassing)

Figure 12. Illustration of radon sources and sinks in a stream-aquifer system (after Agency for toxic substances and disease registry 2010).

Stream discharge at a given point downstream from a given stream segment is calculated as the sum of stream discharge immediately upstream of the given segment plus all groundwater discharge along the segment:

$$Q = Q_0 + \int I$$

Euler's Forward Method is employed to solve the differential equation above.

$$C_{x+1} = \frac{dc_x}{dx} * h + C_x \qquad \text{Step size h (m)}$$

The model was applied along the 3 km stream reach over which radon was measured. (Distances are measured from the north fork weir, so the study reach stretches from 380 m to 3400 m downstream.) The parameters c_i, k, w, and Qo are based upon measured or estimated values, as described below.

Gas Transfer Velocity (k)

The rate at which radon emanates from the stream to the atmosphere (gas transfer velocity, k) is a function primarily of stream turbulence, but also of radon diffusivity, and stream morphology. In previous studies, values for k have been determined through theoretical considerations of stagnant film thickness and through experiments with introduced tracers such as sulfur hexafluoride. COOK et al (2003) and COOK et al (2006) estimate values for the gas transfer velocity (k) by injecting a volatile tracer into the river and measuring downstream concentrations. In both cases, the value for the gas transfer velocity is about 1 m/day. However, the rivers examined in these studies have quite different morphology and flow rates from Squaw Creek. For instance, COOK et al (2003) examines a 117 km long study reach with an upstream discharge of 10 m^3/s (about 10-30 times the discharge on Squaw Creek). In COOK et al (2006), the study reach and discharge are much lower, but the value determined for the gas transfer velocity is very similar. WANNINKHOF et al (1990) use a combination of tritium and sulfur hexafluoride to measure gas transfer velocities on a small stream for about 300 meters. The estimated values of k vary from about 5 to 10 m/d. WANNINKHOF et al (1990) also report a maximum value for groundwater discharge (I) on the order of 14 $m^3/m/day$. ELSINGER and MOORE (1983) use the stagnant film model to calculate gas transfer velocities ranging from 2.1 to 4.1 m/day. The rivers described in both of these studies are much wider, deeper and lower gradient than Squaw Creek.

LLNL and CSUEB carried out a gas tracer experiment in nearby Martis Creek during the summer of 2012. Xenon was introduced to the stream and measured at nine downstream locations over a 1 km reach. The gas transfer velocity was calculated for xenon, and a k value for radon was determined after a slight adjustment for the differing diffusivities of xenon and radon. Calculated values for k only varied slightly between the nine sampling points and averaged 2.50 m/d. Since the flow rates, stream morphology, and stream gradients are similar for the Squaw Creek and Martis Creek study reaches, this value of k was deemed the best estimate for Squaw Creek in July. A somewhat higher gas transfer velocity is expected in June when flow rates are higher and more turbulent. A k value of 4.00 m/d was therefore applied to June data.

The initial concentration of stream radon is taken as the first measured value at the point where the model begins. Discharge data at the same location are not precisely known - the initial flows are taken to be the sum of discharge at the two upstream gauges, averaged over the two day period in June: 1.70 m^3/s, in July: 0.41 m^3/s. A step size (h) of 20 m was applied based on the sampling density of radon. The value for the concentration of radon in groundwater (c_i) was taken as 400 pCi/L based on groundwater activities measured during July 2009. Average stream width (w) is taken as 4 m.

Solving for groundwater inflow

Groundwater discharge (I(x)) per step is input into the model in order to provide a best fit to the observed radon data. Two approaches were taken for fitting the model to the data. The first approach was to interpolate linearly between adjacent measured radon activities, and then fit the model to the resulting curve. The second approach was to fit the model to a polynomial regression of the data. Fitting of the model is performed by inputting values of 'I' that result in stream radon concentrations that most closely match either the polynomial or linear interpolation.

Model Results

Stream radon in the June survey shows a gradual increase in radon activity, requiring a gradual increase in groundwater influx over the study reach. For the parameters outlined above, the model requires an increase in groundwater influx from 1.5 m^3/m/d at 380 m to 4.8 m^3/m/d at 2600 m. The corresponding increase in discharge (Q), from 1.70 m^3/m/d at 380 m to 1.78 m^3/m/day at 2600 m, is half of the increase observed between upstream and downstream gauges (0.16 m^3/s). Additional groundwater input over the reaches outside of the radon study area but within the gauge locations, along with discharge contributions from the tributaries, could account for the balance of the gauged discharge. Groundwater discharge is thus estimated to be about 5% of total stream discharge in June, near the peak of the hydrograph.

In July, the model requires groundwater influx averaging 6.5 m^3/m/d along the reach from 520-1540 m and 2 m^3/m/d from 2500-3000 m. Considering only these groundwater influx sources, stream discharge is predicted to increase from 0.41 m^3/s at 380 m to 0.49 m^3/s at 3400m. This is close to the observed upstream to downstream increase in gauged discharge of approximately 0.08 m^3/s. The longer study reach in July and very low flow in tributaries result in closer agreement between modeled and measured discharge increases in July compared to June. Groundwater input comprises about 18% of total discharge in July. Comparing groundwater inflow percentages using two completely independent methods (radon observations and measured discharge) is useful for assessing the reliability of the gauge data, which is more easily obtained over a long time period, for quantifying groundwater inflow. The results from June and July suggest that using the quantity Q (main stem)-[Q (north fork) +Q (south fork)] overestimates groundwater inflow during period of high runoff and yields a good estimate during periods of lower total discharge. The estimate of 22% annual groundwater inflow for water year 2009 may therefore be considered a maximum.

The apparent changes in radon activity and corresponding changes in groundwater influx along the course of the stream may be the result of analytical uncertainty rather than from actual changes in groundwater discharge or radon emanation. One way of filtering noise from the analytical data is to fit a polynomial to the observed radon concentrations as a function of distance downstream. The polynomial regression effectively smoothes the data and removes analytical artifacts. The linear interpolation method gives each data point equal weight. Both methods were used to match influx, but integrated groundwater discharge is very similar for both the polynomial model and the linear interpolation model.

Large-scale spatial variability in groundwater inflow is likely to be a function of topography, lithology and major geologic structures like faults. Given that the study reach is located within a relatively homogeneous post-glacial floodplain, it is not surprising that stream radon activities indicate that groundwater input into Squaw Creek is for the most part uniformly distributed along the study reach. The lack of major deviations in stream radon activities associated with faulting, combined with determination of mixing ratios of different groundwater components in well samples (SINGLETON AND MORAN, 2010), indicate that groundwater flow along faults comprises only a very small component of total flow.

Conclusions

- Late season flow in subalpine streams like Squaw Creek is supplied primarily by groundwater influx to the stream. Maintenance of baseflow is critically important for moderating water temperature in the creek and for overall stream ecosystem health.
- Comparing discharge measured at two upstream gauges and one downstream gauge along Squaw Creek provides a highly resolved time series to examine groundwater influx. In spite of limitations associated with ungauged tributaries and high variability in flow during peak snowmelt, there is strong evidence that a significant portion of Squaw Creek flow comes from groundwater inflow over much of the year.
- Heat from influx of (slightly warmer) groundwater to Squaw Creek, as measured by Distributed Temperature Sensing, shows that groundwater input is gradual and constant over the 1 km reach studied in June, 2009.
- Surface water and groundwater in Olympic Valley is sourced from meteoric water that falls as snow in the mid-elevation to valley portion of the watershed. Some late season pools show isotopic signatures that indicate evaporating water while others show evidence that they are supplied by groundwater influx.
- Synoptic radon surveys along a 3 km reach of Squaw Creek reveal that the stream is gaining throughout the reach, with groundwater influx making up 5% and 18% of the flow in early June and early July, respectively. The pattern in radon activity indicates that groundwater enters the stream continuously rather than at discrete locations, in spite of the presence of structural features such as faults.

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